RI 8861

Bureau of Mines Report of Investigations/1984

Assessment of Methane Hazards in an Anomalous Zone of a Gulf Coast Salt Dome

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MARCH 3, 1849

UNITED STATES DEPARTMENT OF THE INTERIOR
William P. Clark, Secretary

BUREAU OF MINES
Robert C. Horton, Director

Library of Congress Cataloging in Publication Data:

Assessment of methane hazards in an anomalous zone of a Gulf Coast salt dome.

(Report of investigations ; 8861)

Bibliography: p. 26.

Supt. of Docs. no.: I 28.23:8861.

1. Salt mines and mining—Gulf States—Safety measures. 2. Methane—Safety measures. 3. Salt domes—Gulf States. I. Iannacchione, Anthony T. II. Series: Report of investigations (United States. Bureau of Mines) ; 8861.

TN23.U43 [TN902.A1] 622s [622'.8] 83-600371

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	m^3	cubic meter
cm^3	cubic centimeter	m/min	meter per minute
cm^3/100 g	cubic centimeter per one hundred grams	m^3/d	cubic meter per day
		m^3/h	cubic meter per hour
ft	foot		
		m^3/t	cubic meter per metric ton
ft/min	foot per minute		
		mi	mile
ft^3	cubic foot		
		min	minute
ft^3/d	cubic foot per day		
		min/d	minute per day
ft^3/h	cubic foot per hour		
		kPa	kilopascal
ft^3/ton	cubic foot per short ton		
		ppm	part per million
g	gram		
		pct	percent
h	hour		
		psig	pound per square inch, gage
in	inch		
km	kilometer	s	second
m	meter	t	metric ton

ASSESSMENT OF METHANE HAZARDS IN AN ANOMALOUS ZONE OF A GULF COAST SALT DOME

By A. T. Iannacchione,[1] R. H. Grau III,[2] A. Sainato,[3]
T. M. Kohler,[2] and S. J. Schatzel[1]

ABSTRACT

This Bureau of Mines research study found gas emission rates from an advancing face, and flows and pressure of gas from an exploration drill hole were dependent upon the geology of salt encountered in a domal salt mine. Normal production-grade "pure" salt adjacent to an anomalous•zone was found to have a methane emission rate of less than 5 ft^3/ton (0.1 m^3/t) of mined salt from a room advanced by a continuous miner. Extremely low gas flows [less the 4 ft^3/h (0.1 m^3/h)] and lack of pressure buildup were also observed from this normal salt in a 154-ft (47-m) exploration drill hole. These data indicate that methane emissions should not be a problem when mining in this type of salt.

In the adjacent anomalous zone, methane emission rates ranged from 15 to 70 ft^3/ton (0.4 to 1.8 m^3/t) of mined salt from an advancing face. Gas flows of approximately 42 ft^3/h (1.2 m^3/h), and pressures in excess of 900 psig (6,200 kPa) were observed in an exploration drill hole when the anomalous zone was encountered. This information suggests a greater methane emission hazard from the anomalous zone than from the associated normal salt. If this trend of increasing emissions problems associated with anomalous zones of salt is common with similar anomalous zones encountered or observed in other domal salt mines, then special control strategies should be employed to minimize this potential mining hazard.

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[3] Mining engineering technician.

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INTRODUCTION

This Bureau of Mines study is an assessment of the potential methane hazard to mining of an anomalous zone in a Louisiana domal salt mine. Detailed geologic mapping, emissions studies, physical properties tests related to gas, and methane content of salt samples from an anomalous zone encountered at the Belle Isle Mine are presented and provide a basis for discussion of a control strategy for this particular problem area (fig. 1).

Although methane (CH_4) has long been recognized as a hazard in coal mining, the danger it poses in domal salt mines has only recently become apparent. Throughout the history of mining salt in the Gulf Coast region, hazardous methane emissions have occurred at infrequent intervals. The inconsistent nature of the methane problem has detracted from the seriousness of the hazard and, consequently, hindered the development of control strategies and procedures. Analogies can be drawn with the early coal mining experience in the United States. Prior to the Federal Coal Mine Health and Safety Act of 1969, coal mines could be classified as either gassy or nongassy. However, history has shown some of the worst coal mine methane-induced explosions have occurred in mines originally classified as "nongassy" (1).[4]

Recently, new blasting techniques, deeper mining levels, and higher extraction rates have increased the frequency of hazardous methane occurrences. These occurrences have sometimes been manifested as violent outbursts of methane and salt. Outbursts are generally associated with blasting, but occur only in a small fraction of the total number of faces. However, these hazardous methane emissions have often occurred in groups and are sometimes associated within regions or specific zones within several of the domal salt mines.

This report shows an association of a methane occurrence with certain salt characteristics. The recognition and prediction of these areas can reduce the potential for hazardous methane emission problems by developing special control procedures and techniques.

METHANE IN DOMAL SALT MINES

The unique geologic and physical characteristics of domal salt mines have influenced the occurrence of hazardous methane conditions. Previous investigations (2-6) have determined some of the characteristics of a violent outburst of salt, which often results in hazardous methane conditions. Our investigation deals with the occurrence and characteristics of some types of gassy salt. The sections that follow will examine some of the geologic and physical properties associated with gassy salt and propose a control strategy for this potential hazard.

GEOLOGIC AND ENGINEERING CONSIDERATIONS

Salt domes of the Gulf Coast region have elliptical or circular shapes and taper at depth. Tops of individual salt stocks range in diameter from 1 to 5 mi (2 to 8 km). Dome flanks vary from vertical to inclined with sharp to gradational contacts with country rock (7).

Salt bands with thickness ranging from 0.5 in (1 cm) to 3 ft (1 m), reveal the dominant orientations of a diapiric structure. The salt within the domes has been so intensely folded that the bands are nearly vertical (5, 8-9). Therefore, as the mine develops horizontally, it advances through band after band of nearly vertically bedded salt. Multiple-level development should penetrate similar layers of salt at the same relative location (depending on the dip of the bands).

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[4] Underlined numbers in parentheses refer to items in the list of references at the end of of this report.

Distinct colors of bands are associated with insoluble impurities, predominately anhydrite with minor amounts of dolomite, calcite, and quartz.

The massive diapiric nature of these domes has afforded the unique opportunity to drive large underground openings. Advancing mine sections are routinely

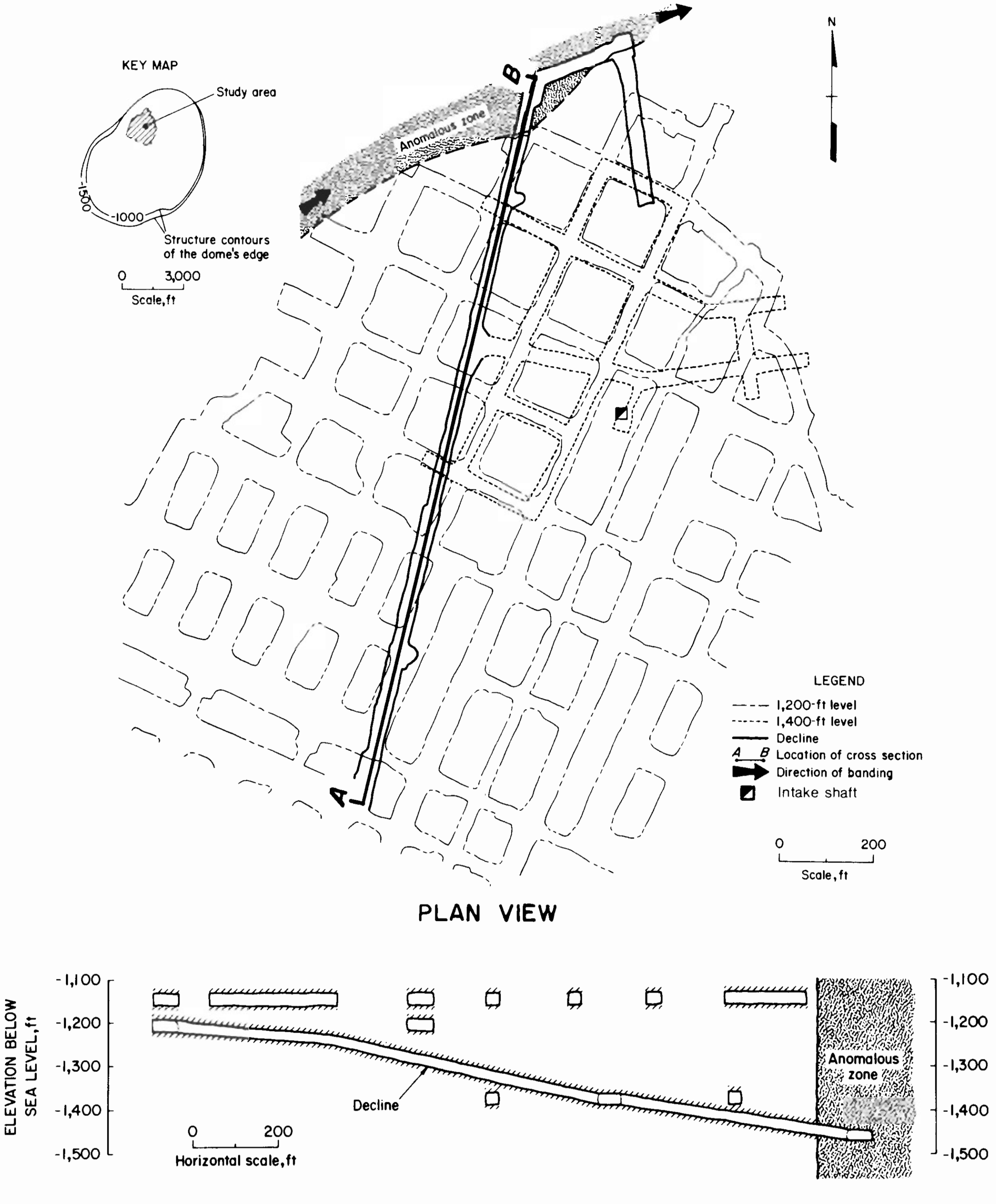

FIGURE 1. - Plan and cross-sectional view of study area within Belle Isle salt mine.

developed by blasting to a height of 35 ft (11 m) and a width of 30 to 100 ft (10 to 30 m). Benched areas range from 60 to 120 ft (20 to 36 m) high.

OCCURRENCE OF ANOMALOUS ZONES

Anomalous types of salt, different in composition from normal salt (99 pct pure halite), have been associated with mining problems. Zones of anomalous salt can be identified from the more common normal salt by several of the following characteristics: (1) brine and gas seeps, (2) presence of clastic material, (3) shearing, (4) recrystallization, (5) expansion joints, and (6) association with outbursts (10). The anomalous salt zone of this study is characterized mainly by fluid flows, predominently in the form of methane gas and brine, and the increased occurrence of sandstone, shale, and clay material, causing the overall salt mass to appear dark in color.

The origin of the anomalous zones may be tied to the concept that salt domes consist of many stocks or spines of salt that have risen separately through time at varying rates (10-11). The marginal areas of these "spines" are defined by clastic gouge material, which is included into the salt core. It has been suggested that the spines move upward at different rates, incorporating the spines with their associated anomalous zones into the central portion of the dome. Because many of these anomalous zones are comprised of country rock rich in organic and inorganic solids and liquids, they are recognized underground as zones that differ significantly from those of normal salt. Kupfer (11) has identified anomalous zones in four of the five sister domal salt mines operated in southern Louisiana. He has also indicated that outbursts often occur along linear zones that are associated with clastics, liquids, gases, fluid inclusions, shearing, and abnormally dark salt.

THE OUTBURST PROBLEM

Outbursts, violent explosions of salt-rock and gas released under high pressure, have been known to occur within domal salt mines for many years. The association between outbursts and large emissions of methane and other gases have been documented in several reports (2, 4-6). The hazard resulting from a rapid release of large volumes of methane and the subsequent inundation of an entire mine, which may last several days, has induced much discussion about the resultant danger and the proper techniques to safely and effectively deal with it.

It is generally accepted that outbursts occur during or shortly after blasting of a salt face. Thoms (12) has implied that the driving force for an outburst in salt is entrapped gas. Other theories attributed high rock stresses as the dominating force.

A salt outburst creates a cavity in the roof or rib area that generally extends vertically upward (fig. 2). These openings range from 3 ft (1 m) to 30 ft (10 m) in diameter and 3 ft (1 m) to greater than 70 ft (22 m) in height. Outbursts observed at the Jefferson Island Mine were in the same relative position at both the 1,300-ft (400-m) and 1,500-ft (460-m) levels. This is attributed to the near vertical orientation of a very gassy zone of salt.

INVESTIGATIONS OF ANOMALOUS ZONE AT BELLE ISLE MINE

An anomalous zone within the Belle Isle Mine was investigated in detail to (1) correlate specific gas emissions with particular salt types, (2) compare physical properties related to gas of normal and anomalous salt zones and (3) evaluate the usefulness of this data in predicting the location of potential problem areas within the mine.

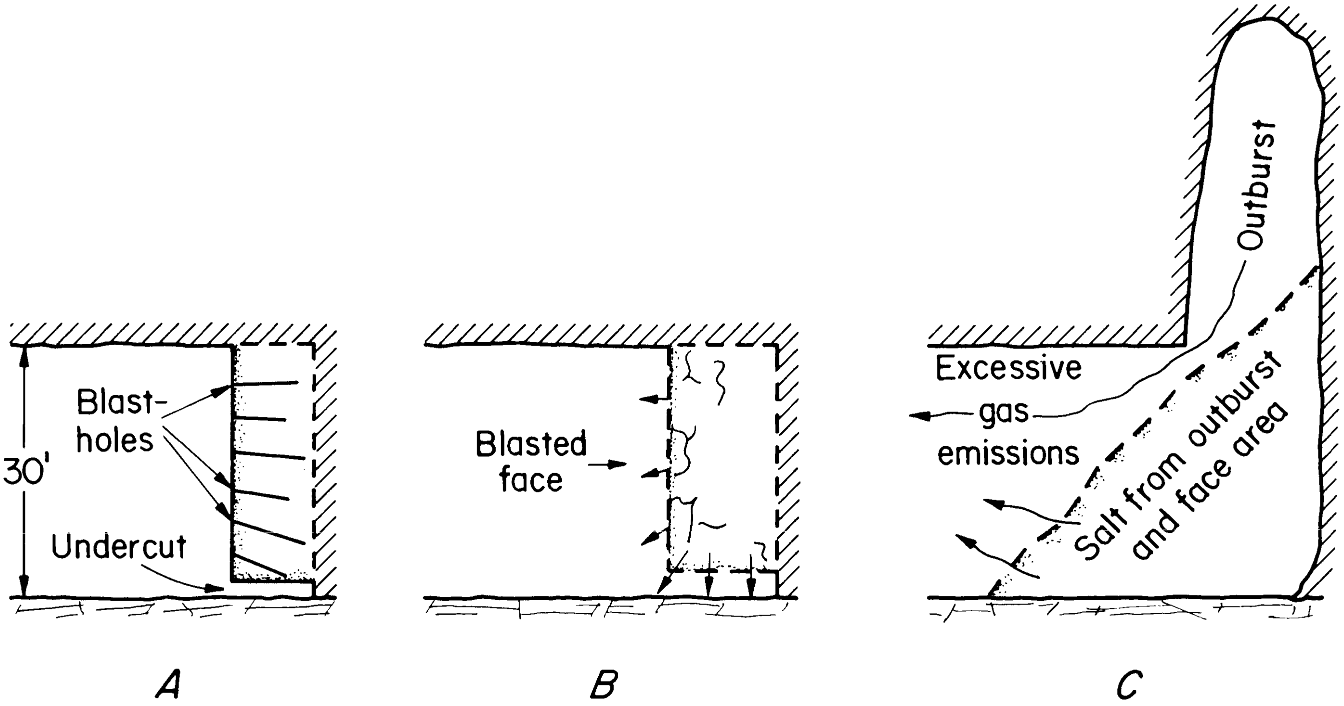

FIGURE 2. - Sequence of events associated with typical outburst triggered by blasting.

EMISSIONS FROM BLASTED FACES IN ADJACENT NORMAL SALT

Before presenting results of the emissions study conducted in the anomalous zone, we must understand the relative gas emissions experienced during typical production face advancement in the normal salt adjacent to the anomalous zone. Estimation of gas emissions from large blasted faces is complicated by the withdrawal of all personnel from the mine during blasting and lack of discernable persistent air currents within many face areas. Therefore, our results can be taken only as an indication of gas concentrations after blasting. Two mine-face areas in normal salt adjacent to the anomalous zone were sampled immediately after a blast to determine the approximate concentrations of gases present.

Gas sampling was accomplished by using a permissible sequential gas sampler (fig. 3). This pneumatically operated device designed for this express purpose is actuated by the pressure wave from the face blast. The blast wave moves an air vane connected to a blast-operated switch (fig. 4) that initiates a timing sequence within a control box. Once the preset time is reached, a pneumatic signal is sent to the sampling unit (fig. 4), which opens a pneumatically operated valve releasing liquid from the sample chamber so that ambient air can replace it. This system is designed to collect a series of gas samples at different time intervals. These samples can be analyzed at a later time.

The sequential gas sampler was first tested at a blasted face on the 1,400 ft (430 m) level approximately 650 ft (200 m) from the anomalous zone. Face dimensions were 26 ft (8 m) by 32 ft (10 m). Approximately 160 ft/min (49 m/min) of air was moving through the entry in which the sampler was placed (fig. 5). This entry is approximately 50 ft (15 m) from the blasted face area. During the face blast, the intake fan was deenergized to prevent damage by the overpressure wave from the blast. Approximately 5 to 10 s after the blast, the surface fan was turned on again. The blast caused the air to move from the face, up the intake shaft, then back down the shaft, and to recirculate past the sampler (fig. 6). The point of interest here is that

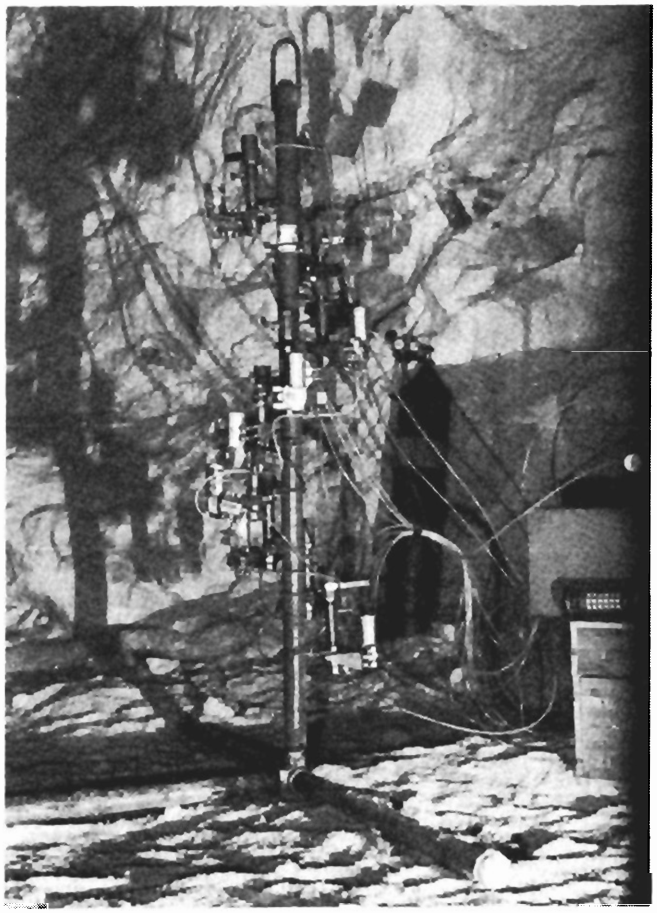

FIGURE 3. - Pneumatically operated sequential gas sampler designed to collect ambient air samples during and after blasting.

maximum concentrations of methane detected in the air samples collected at the blasted face were less than 0.01 pct (table 1).

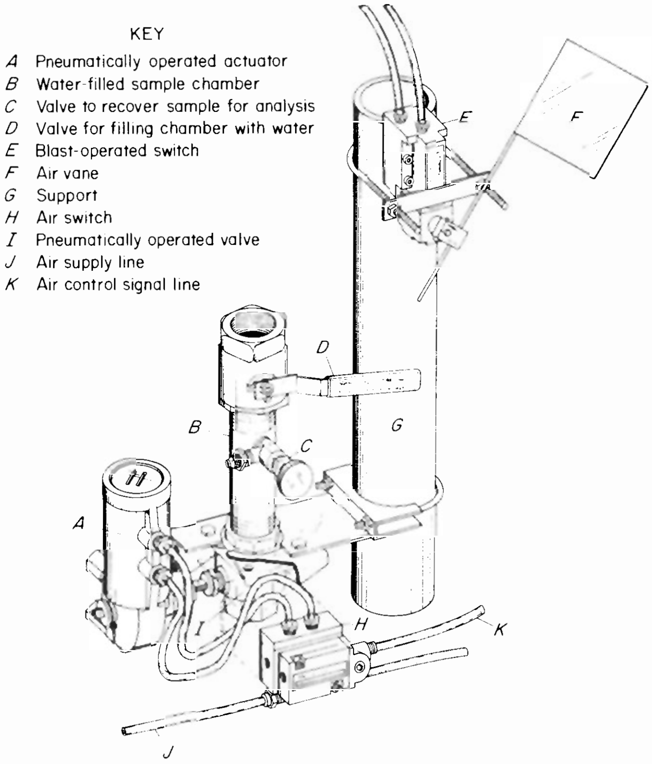

FIGURE 4. - Pneumatic gravity switch and gas-sampling unit.

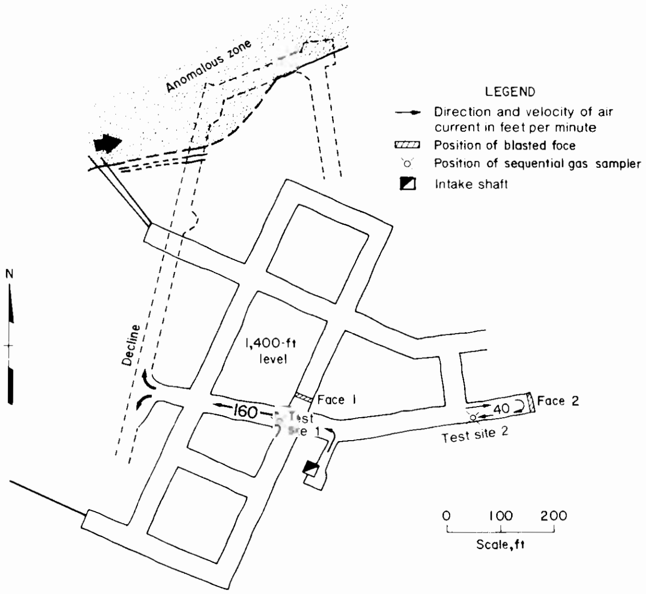

FIGURE 5. - Location of sequential gas sampler test sites.

The second test of the sequential gas sampler was also conducted on the 1,400-ft (430-m) level but at a distance of approximately 750 ft (230 m) from the anomalous zone (fig. 5). The room dimensions were similar to those of test 1 [22 by 35 ft (7 by 11 m)], but the ventilating air currents were extremely slow. Smoke tube surveys at the sampling locations indicated a velocity of approximately 40 ft/min (12 m/min). However, at other locations within this face area, relative magnitudes and directions of air currents varied. Analyses of the samples collected from the tests are shown in table 1. Figure 7 shows the change in concentrations of methane after the blast. The maximum methane concentration at the sampling location was found to be

0.004 pct. The average methane concentration for 30 min after the blast was 0.003 pct.

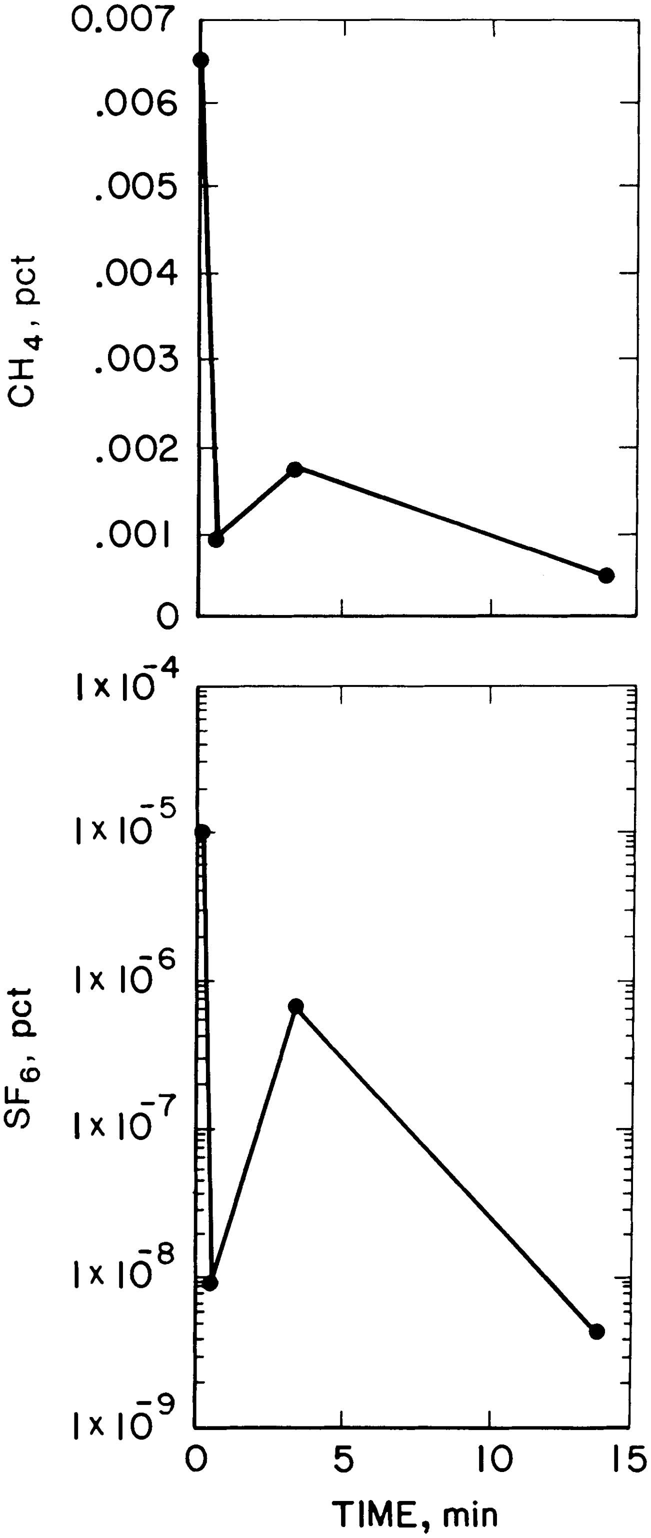

FIGURE 6. - Gas concentrations from test site 1.

Sulfur hexafluoride (SF_6) was used as a tracer gas in both tests to check the reliability of the sampling system. The

TABLE 1. - Analysis of gas samples collected from blasted faces

Sample	CH_4, pct	SF_6, pct	Time, s
TEST 1, NOV. 17, 1981			
1	0.0066	9.9×10^{-6}	3
2	.0009	9.05×10^{-9}	24
3	.0018	5.5×10^{-7}	209
4	.0045	3.5×10^{-9}	827
TEST 2, APR. 21, 1982			
1	0.0028	3.6×10^{-8}	18
2	.0022	5.3×10^{-8}	45
3	.0024	6×10^{-9}	89
4	.0024	5.57×10^{-9}	156
5	.004	6.55×10^{-9}	275
6	.002	2.52×10^{-9}	460
7	.0019	1.43×10^{-9}	657
8	.0028	5.65×10^{-10}	832
9	.0021	5.5×10^{-10}	996
10	.0027	5×10^{-10}	3,060
11	.002	1.55×10^{-10}	3,420
12	.0017	1.43×10^{-10}	4,020
13	.001	1.1×10^{-10}	4,320
14	.0009	3.05×10^{-10}	5,100

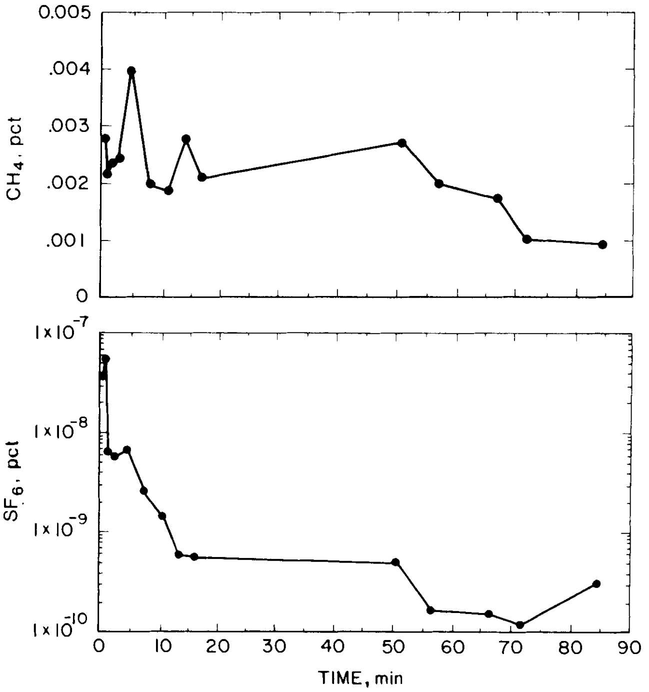

FIGURE 7. - Gas concentrations from test site 2.

SF_6 was placed in plastic bags and secured to the face before blasting. The blast ruptured the bags, releasing the tracer gas. Figures 6 and 7 show corresponding peaks of SF_6 concentration with methane concentration at both test sites. This information is shown simply as a check on the gas concentration data.

Although these two tests are not conclusive, the data do show that extremely low gas emissions were found during blasting of normal salt located adjacent to the anomalous zone.

METHANE EMISSION STUDY THROUGH AN ANOMALOUS ZONE

Investigations conducted in the Belle Isle Mine decline area have shown that much higher methane emission rates are associated with anomalous zones of salt than those emission rates determined for normal salt. The decline was advanced from normal production grade salt into a "low production grade" (wet-argillaceous) salt (fig. 8), then back again into the normal salt (fig. 9). This area of low-grade salt has been interpreted as an anomalous zone, using the characteristics defined by Kupfer (10). This study site, therefore, provided an excellent opportunity to determine specific changes in emission rates with changing geology.

Methane emission data from advancing faces in domal salt mines are virtually nonexistent because of the great difficulty in measuring ventilation patterns in large cross-sectional rooms with low air velocities. The advancing face in the decline possessed the advantages of a relatively small room size [13 ft by 30 ft (4 m by 9 m)] and a well-defined ventilation pattern from a 30-in rigid exhaust duct (fig. 10) to remove air from

FIGURE 8. - Low-production-grade (wet-argillaceous) salt within anomalous zone of the decline.

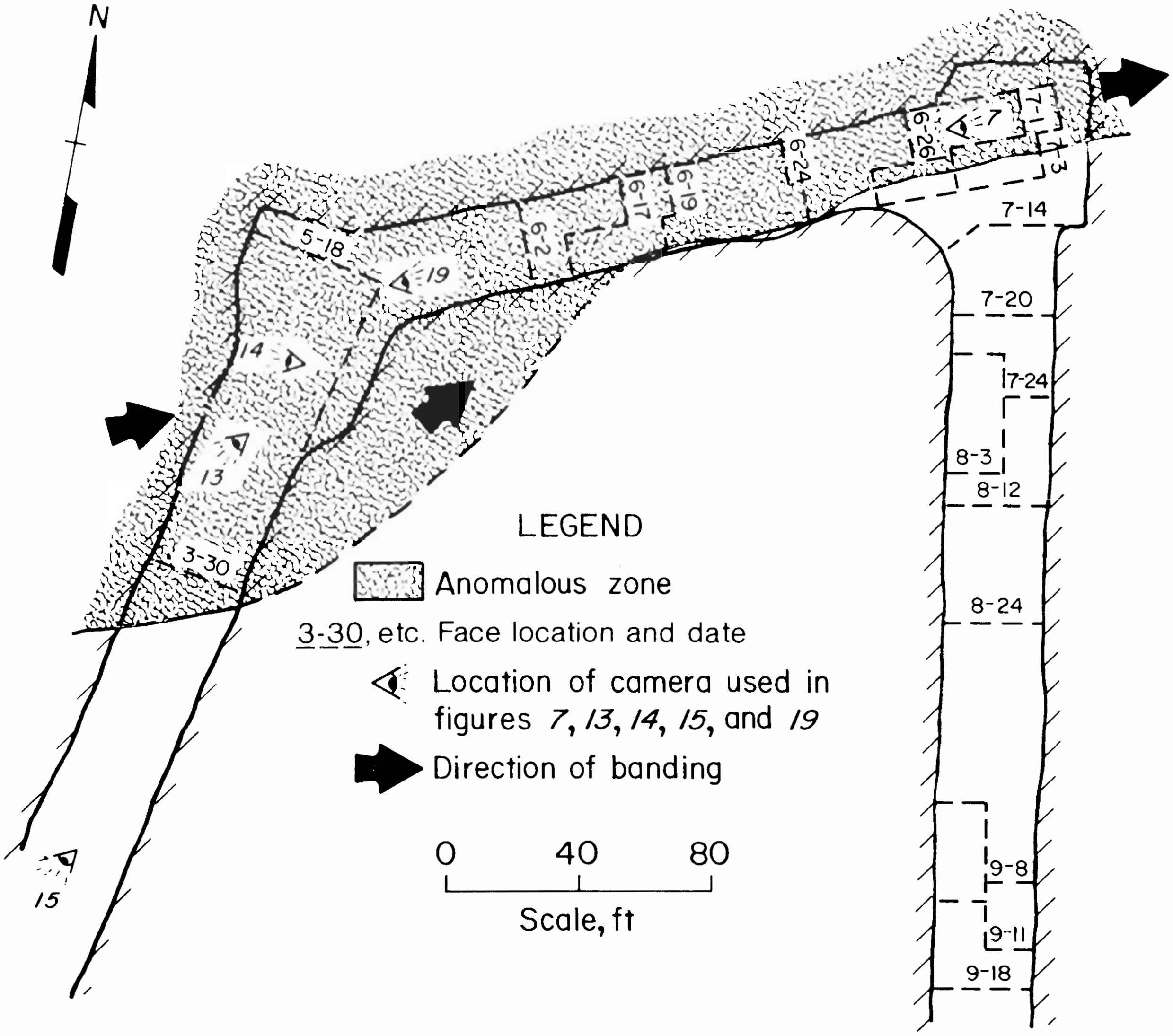

FIGURE 9. - Plan view of location of anomalous zone and various positions of decline face during emissions study.

the face. Also, the face was driven by a continuous miner as opposed to a conventional mining system. Conventional mining, with the use of explosives to blast production faces, prevents emission-rate studies because of the short-term disruption of low-velocity air currents by pressure waves from the blast. The use of the continuous-mining system did not disrupt ventilation patterns.

A monitoring system capable of recording velocity and methane concentrations was placed in the exhaust duct (fig. 11). An additional methane-sampling system, composed of a vacuum pump and methane sensor (fig. 12), withdrew a gas sample from the duct for comparison with the methane concentration recorded by the other sensor located in the duct. Fresh air was sampled from a third position to determine intake-air quality (fig. 13). Periodically, gas samples were collected in evacuated tubes for chromatagraphic determination of gas concentrations. Also, numerous ventilation surveys were conducted to determine average velocities and air quantities within the study area.

The salt within the anomalous zone study area is dark, argillaceous, wet and gassy. Dissolution analysis conducted by Schatzel and Hyman (13) showed the methane content to average approximately 0.33

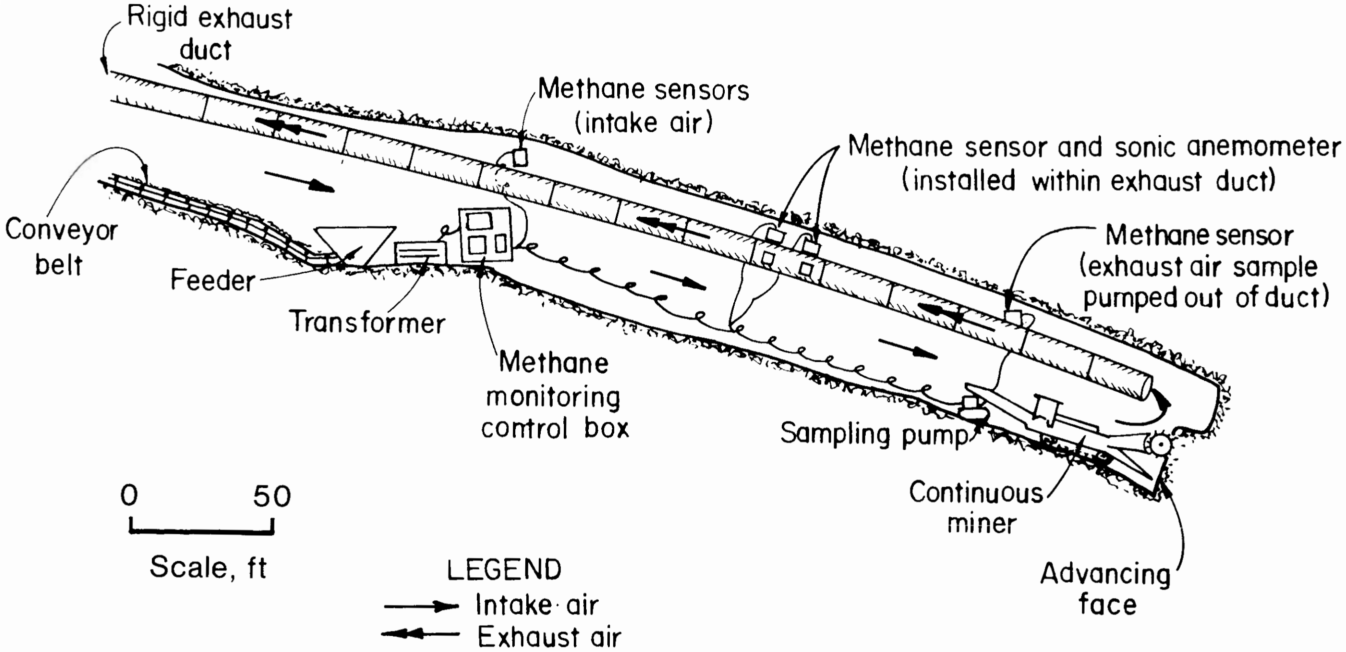

FIGURE 10. - Cross-sectional view of advancing face of the decline with ventilation pattern and position of monitoring equipment.

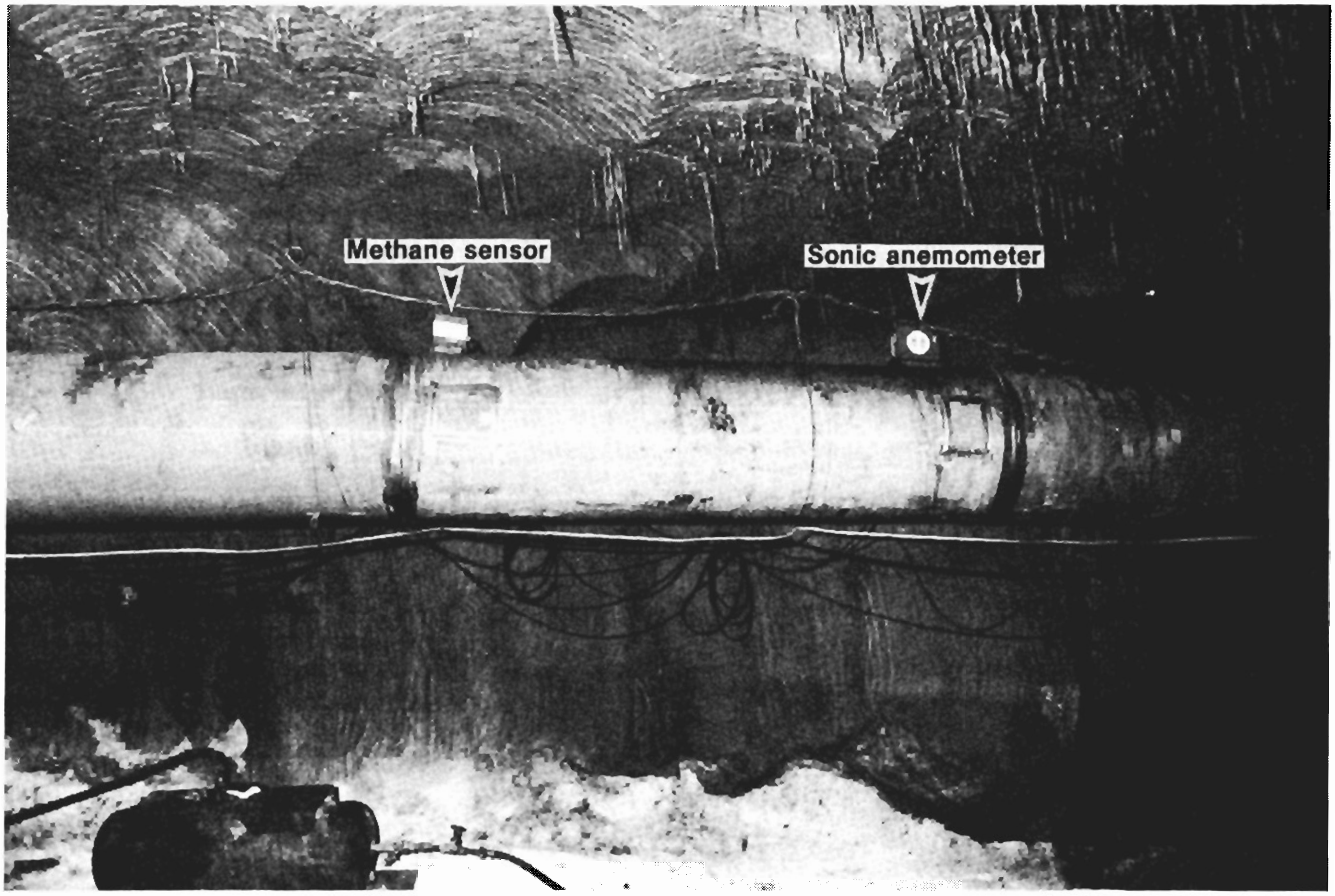

FIGURE 11. - Methane sensor and sonic anemometer within exhaust duct.

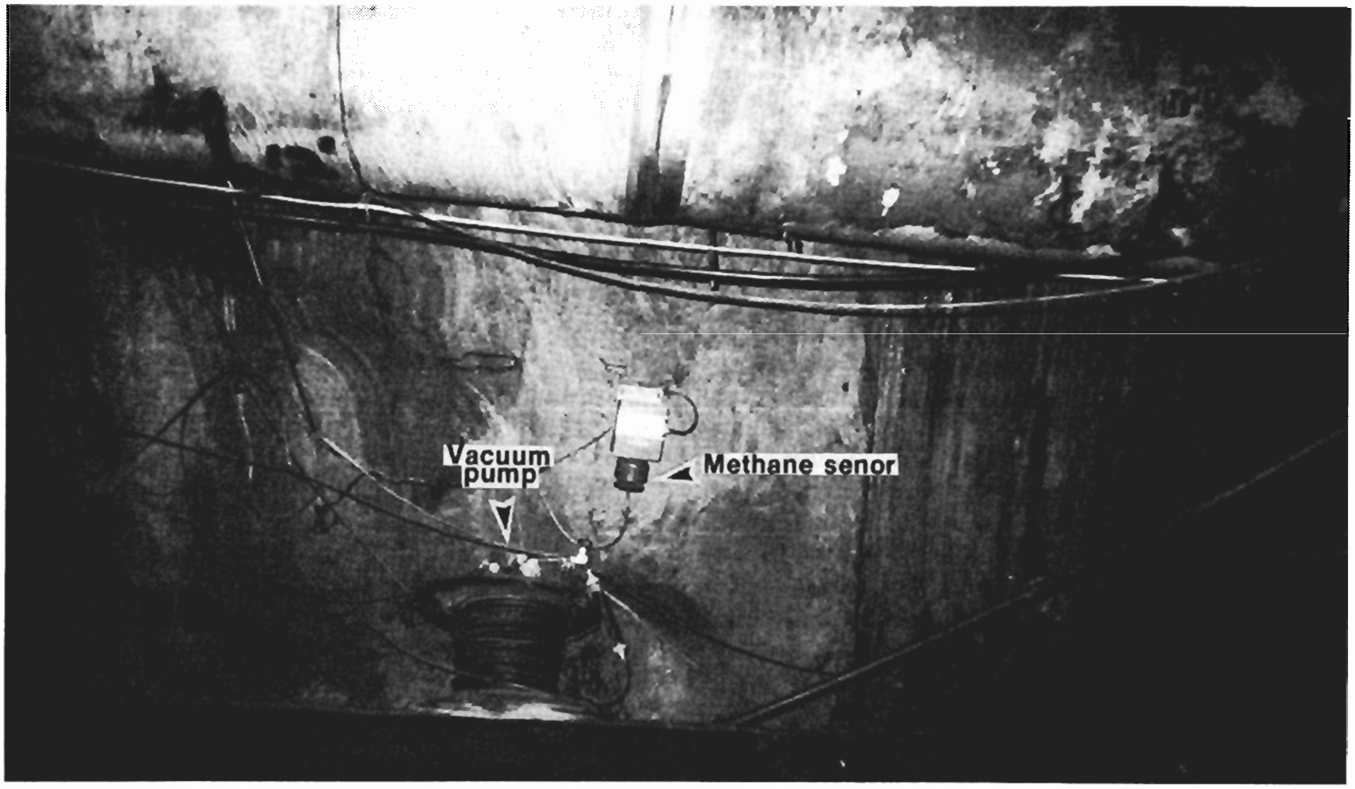

FIGURE 12. - Vacuum pump and methane sensor for collecting and measuring methane concentration in exhaust duct.

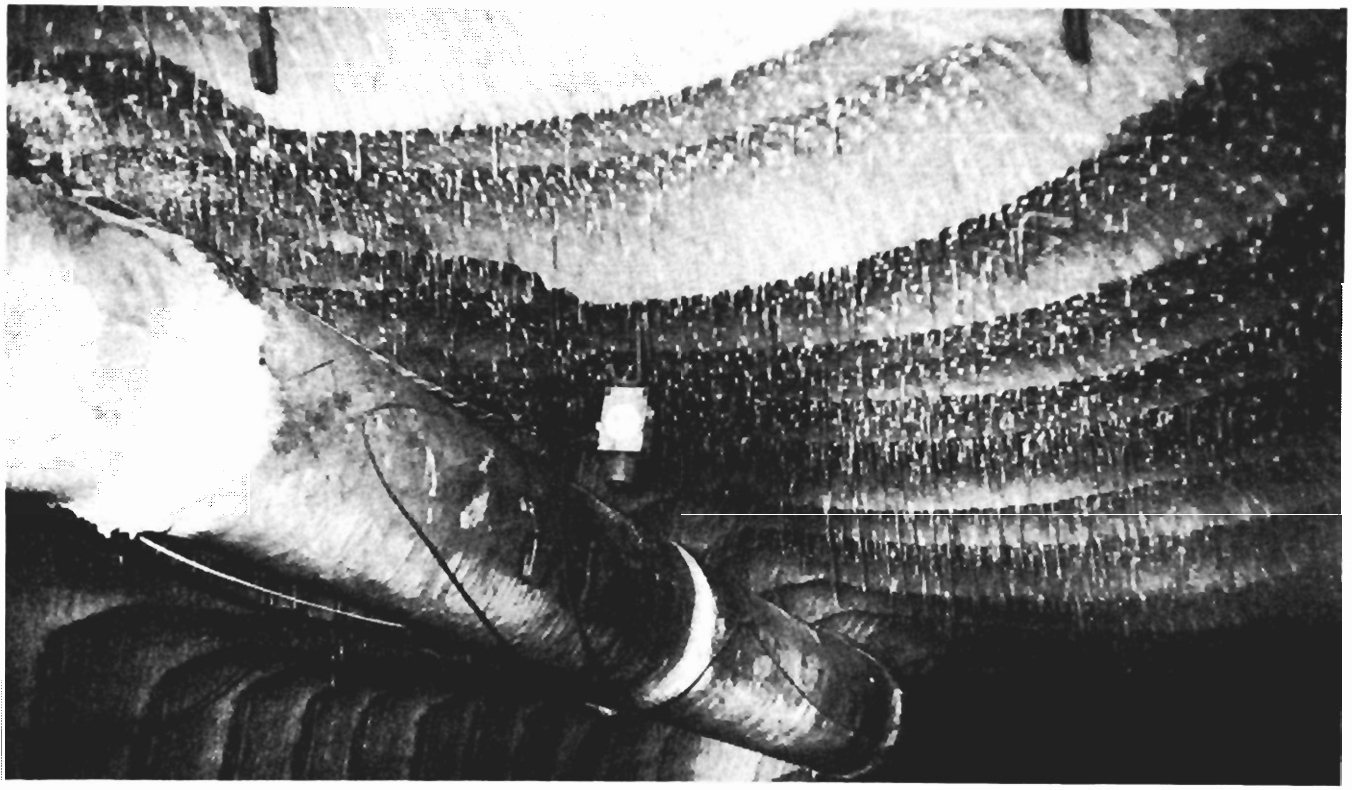

FIGURE 13. - Intake-air methane sensor.

ft^3/ton (1.034 cm^3/100 g) within the anomalous salt of the study area. Normal salt methane contents were found to be far less, averaging approximately 0.0015 ft^3/ton (0.0046 cm^3/100 g). Locations and analyses of these data are shown in figure 14.

This emission study was conducted from March 30, 1981, to September 9, 1981. Emissions occurring after July 3 will be referred to only in a general manner to explain certain interesting phenomena. However, the addition of a 30-in (76-cm) blowing duct and fan to the decline at the beginning of July complicated sampling procedures and prevented accurate measurements of air quantities. Therefore, only production days from March 30 to July 3 were used to calculate methane emission rates.

Emission-rate determinations were made during the first 47 production days. The amount of methane emitted during the 47 days ranged from 107,000 to 131,000 ft^3 (3,030 to 3,710 m^3) of methane. Approximately 5,000 tons (4,540 t) of salt was hauled from the face during the 47 days. Daily totals of methane emitted during production are shown in figure 15.

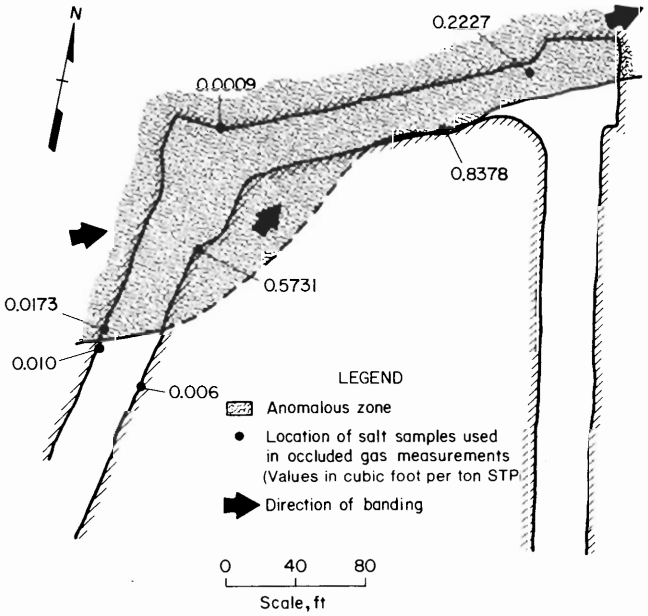

FIGURE 14. - Location and concentration of methane contents from salt samples collected in decline area.

Ninety percent of the production during this time was from the anomolous zone. The average methane emitted per production day within the anomalous zone was approximately 2,500 ft^3 (71 m^3), but the average for the transitional zone to normal salt was generally less than 500 ft^3 (14 m^3). Because production rates varied significantly, the quantities of methane emitted per ton of salt mined per day is thought to be a more meaningful qualitative indicator of methane emission. Methane emission rates in the normal salt after July 3 were generally undetectable.

Estimations of emission rates versus tonnage are based on reliable production data for salt mined from the face per shift. The procedure used is presented in greater detail in a previous study to estimate salt produced per day (14). By comparing the total amount of salt hauled from the face per day with the amount of production time per day, we were able to estimate a production rate for the advancing face (fig. 16). Production times could be estimated by the abnormal readings from the sonic anemometer within the exhaust duct (fig. 17). Apparently, salt dust produced during mining causes erratic velocity measurements as compared to the consistent velocity measurement during nonproductive periods. Therefore, emission rates (ft^3/ton; m^3/t) were estimated by comparing the minimum and maximum values of methane emitted per day (fig. 15) with the total estimated tons of salt produced per day (fig. 16). Figure 18 shows the emission rates based on the estimated tons mined for each of the 47 production days for which reliable data were available.

Analyses of the data shows (1) a decrease in the emission rate occurred between March 30 to July 3 as the normal salt was approached, (2) an increase in emission rate when mining perpendicular to rather than parallel to the direction of banding, (3) and a correlation between emission rates with methane content data. The emission rate within the anomalous zone averaged 27.3 ft^3/ton (0.7 m^3/t) of mined salt, but the rate dropped to less

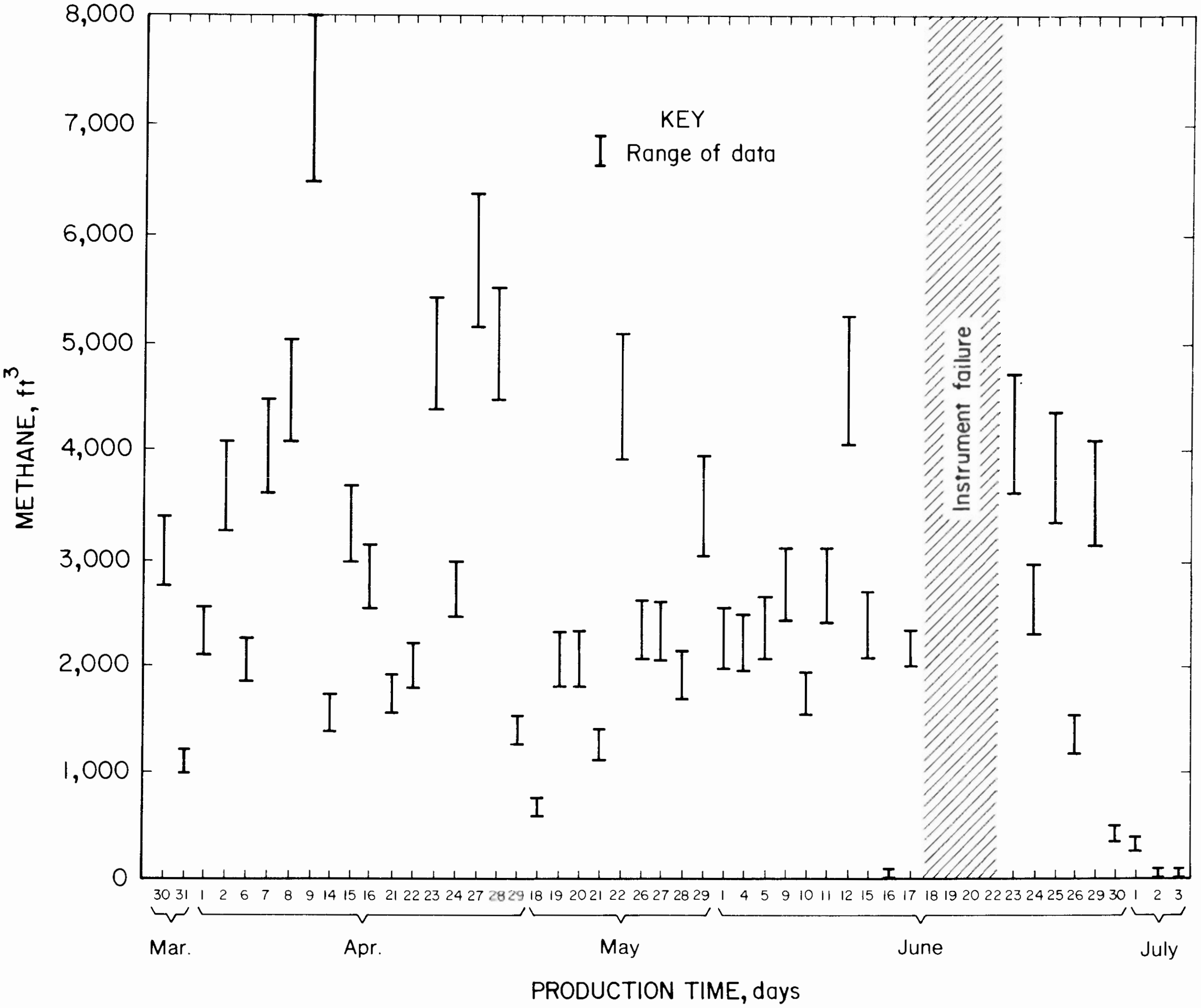

FIGURE 15. - Amount of methane emitted per day for 47 production dates from March 30 to July 3.

than 5 ft^3/ton (0.1 m^3/t) of mined salt for the transition zone to normal salt. Figure 9 shows the position of the face during the later part of June and beginning of July when the transition to normal salt was mined.

There was a 44-pct decrease in emission rates as the face advanced parallel to the banding as opposed to when the face advanced at an angle to banding. This may be caused by an enhanced drainage of gas from the strata due to permeability where fractures intersect perpendicular rather than parallel to the face. The average emission rate from March 30 to May 19 was approximately 37.5 ft^3/ton (1.0 m^3/t) of mined salt. The angle between the banding at the salt face and the orientation of face advancement for this first period was 40 to 80 deg, while the orientation of the banding in the salt and the face advancement were approximately parallel for the second period (fig. 19). The second period (May 20 to July 1) had an average emission rate of 20.9 ft^3/ton (0.5 m^3/t) of mined salt. Figure 9 shows that on approximately May 19 the face made a sharp turn to the east and essentially followed the salt bands until a second turn occurred at July 1. The association of anomalous salt with measurable methane emissions is shown in figure 20.

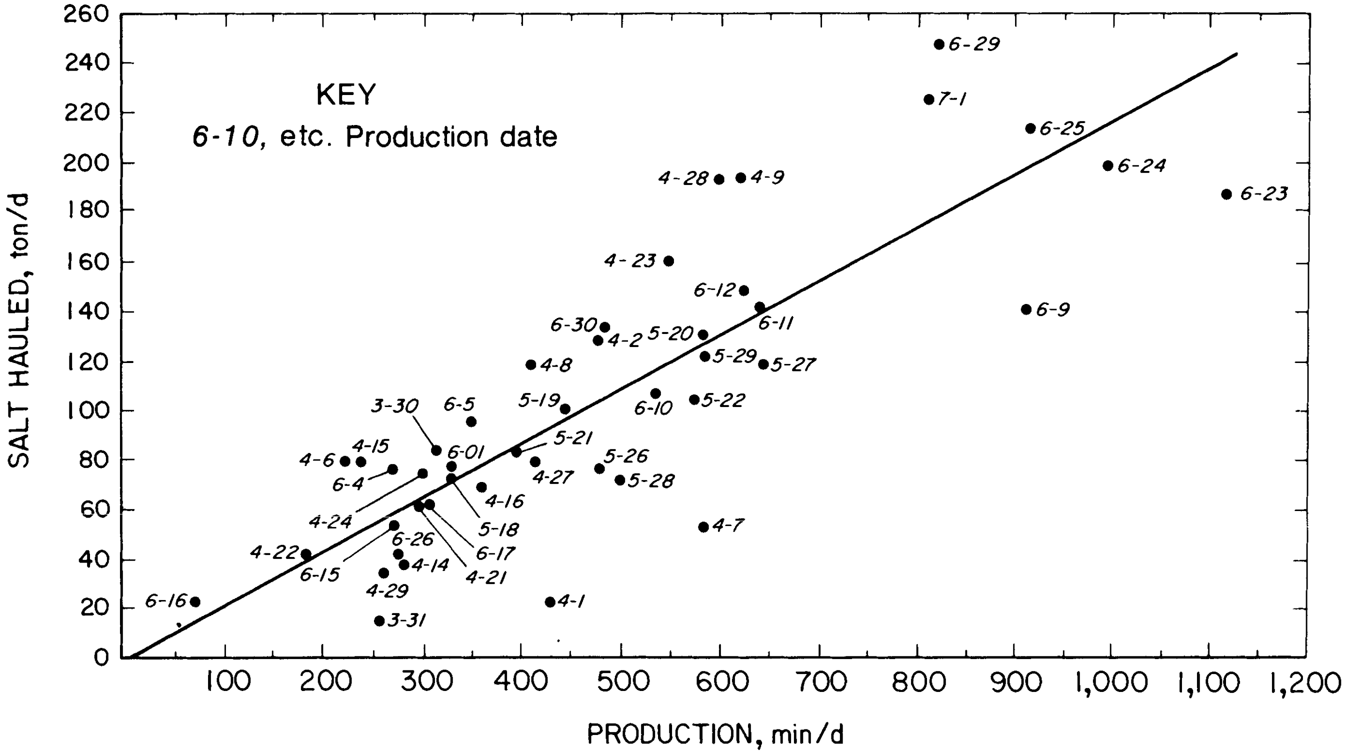

FIGURE 16. - Salt production rate from decline as a function of salt hauled versus production time.

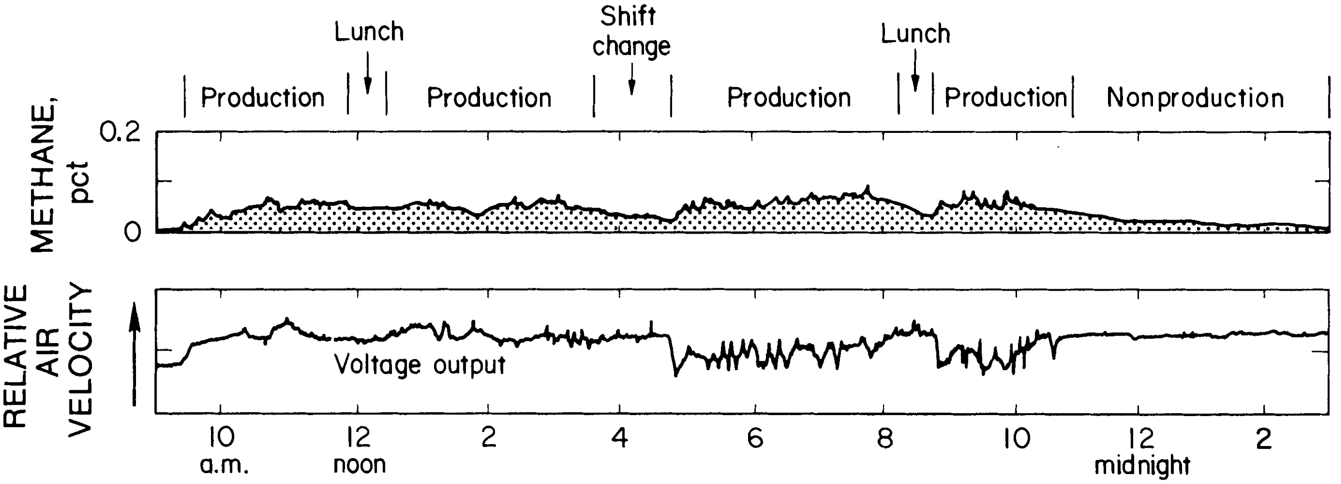

FIGURE 17. - Strip chart recording from methane sensor and sonic anemometer within exhaust duct. Notice the correlation between methane concentration and anomalous responses from the sonic anemometer.

Comparison of these emission data with the methane content data developed by Schatzel and Hyman (13), also suggests permeability within this anomalous zone. The difference between the methane content and the average measured emission rates for the sampled area is 80 times greater [0.33 to 27.3 ft^3/ton (0.009 to 0.7 m^3/t)]. Some of the reasons for this can be attributed to the differences in sample size and physical conditions under which the data are estimated. However, the large differences between these two sets of data indicate that the methane content of salt at the face cannot account for a significant portion of the

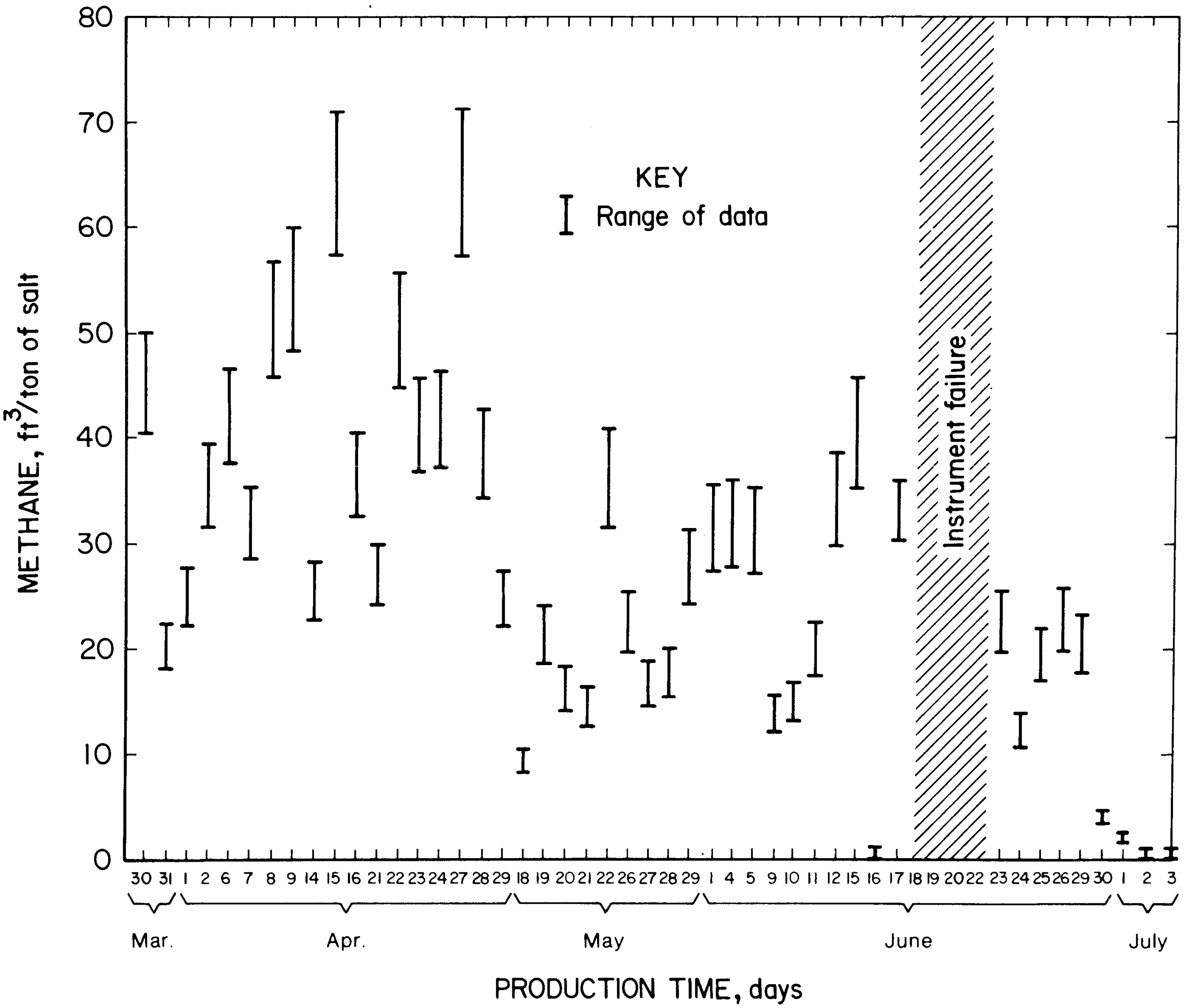

FIGURE 18. - Calculated methane emission rates per ton of salt produced from the decline face from March 30 to July 3.

methane emitted into the air exhausted from the face. Permeability would allow for a larger reservoir from which methane could drain during advancement of the face. This is an important consideration since domal salt is generally thought of as impermeable. Previous investigations by Thoms in an area of normal production grade salt at the Jefferson Island (12) Mine have shown in situ permeability to be nearly zero, with only some mining-induced permeability observed near free faces of salt pillars.

Reliable determination of emission rates were not possible after July 3 because of the addition of a flexible blowing air duct in the decline. This addition to the ventilation system disrupted the continuous, even flow of air down the decline, across the face, and back up the decline through the rigid exhaust duct. When the booster blowing air duct was forcing air down the decline, the entry itself probably had recirculation. There is some evidence that one current of air was moving down the decline along the

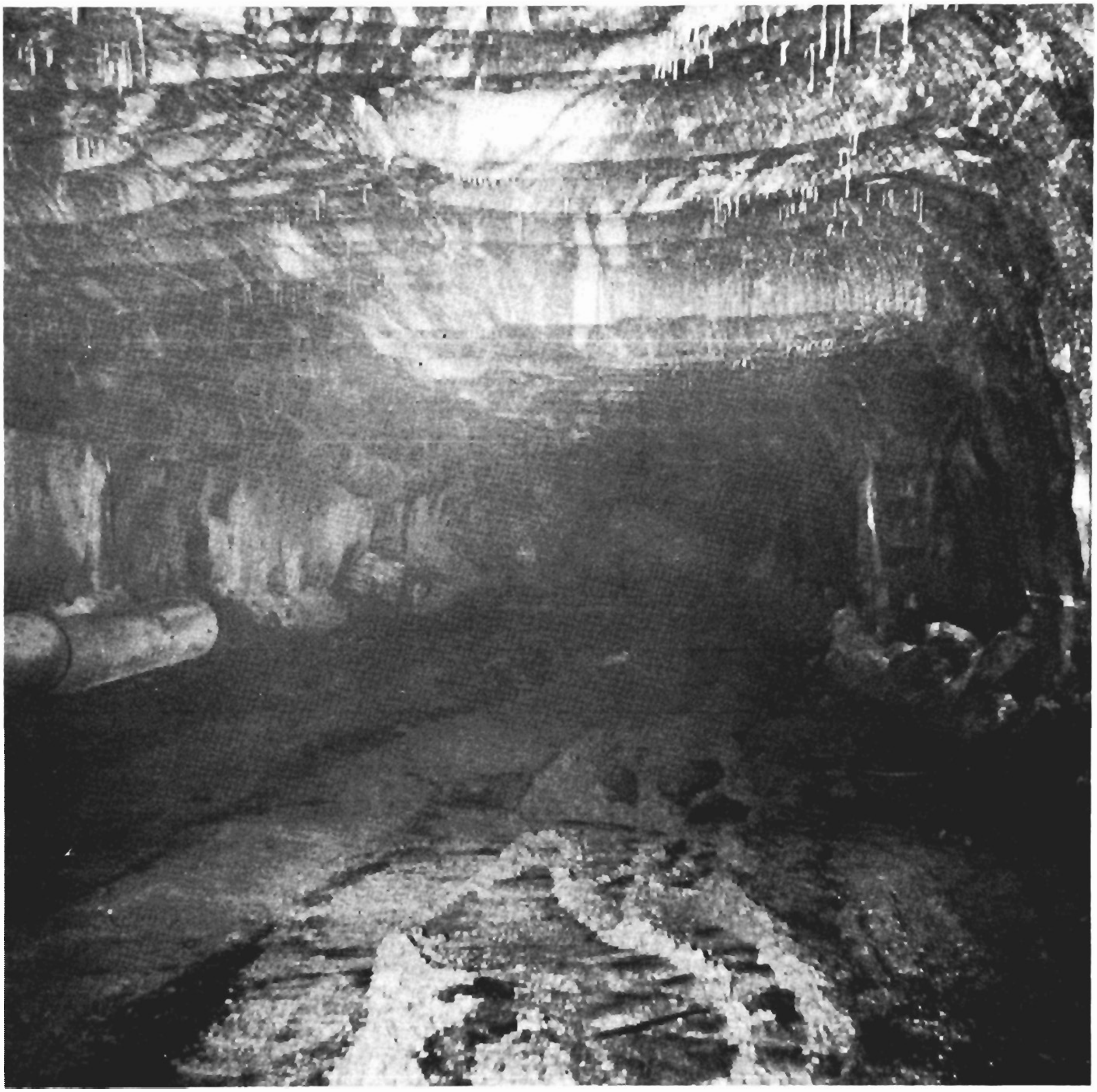

FIGURE 19. - Area within the decline where banding is parallel with entry.

bottom of the entry while simultaneously another current of air was moving up the entry along the roof. Also, the auxiliary ventilation systems would reduce the overall velocity of the current of air moving down the entry.

The intake air currents split at the face, with one portion being exhausted from the decline through the rigid duct and another portion moving away from the face along the entry roof. The location of the entry sensor is shown in figure 20. During the several production days after July 3 precise analyses of gas samples showed concentrations of methane were similar at both the exhaust duct sensor and the entry sensor. Strip chart

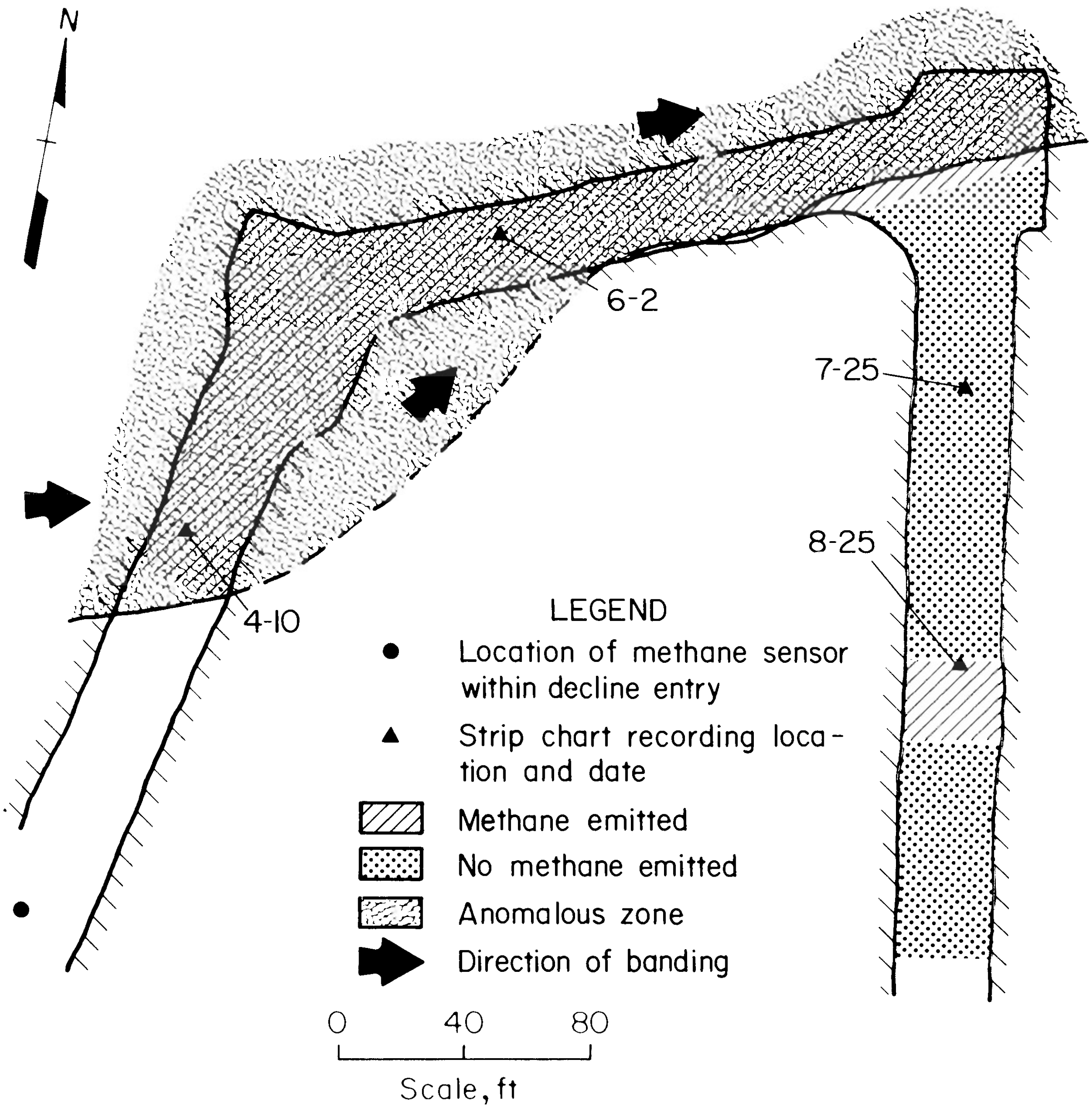

FIGURE 20. - Plan view of face areas where methane emissions were detected.

recordings from methane sensors during several of the production days show this similarity in concentrations (fig. 21). This data confirms split air currents in the decline entry after July due to the addition of auxiliary ventilation.

During another short period (July 25-26) when the face was advancing through the normal salt, an interesting methane emission phenomenon was observed. Over the weekend, when there was no production at the face, methane was measured by the sensor in the entry and not by the sensor in the exhaust duct (fig. 22). Since the sensor in the exhaust duct was measuring the air directly from the face area, we assume the emissions from the face were close to zero. However, during this same period, the sensor in the entry, which was probably analyzing the air moving up the decline away from the face, had a methane concentration of approximately 0.05 pct. A possible explanation of this phenomenon is that the rib within the anomalous zone away from the face area

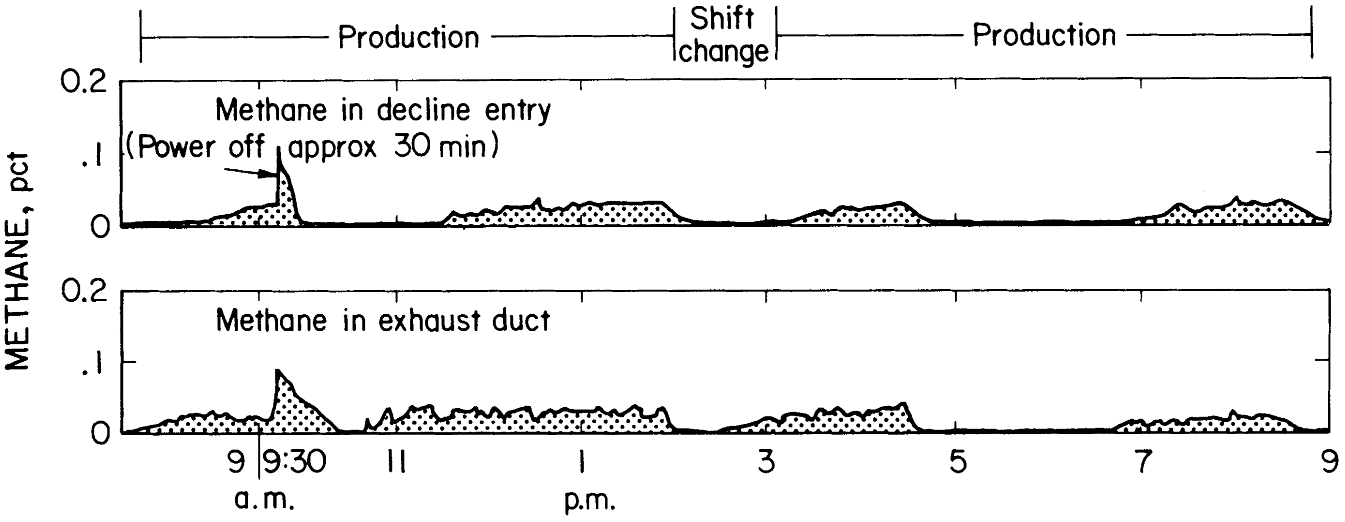

FIGURE 21. - Strip chart recordings from entry and exhaust duct sensors showing similar methane concentrations.

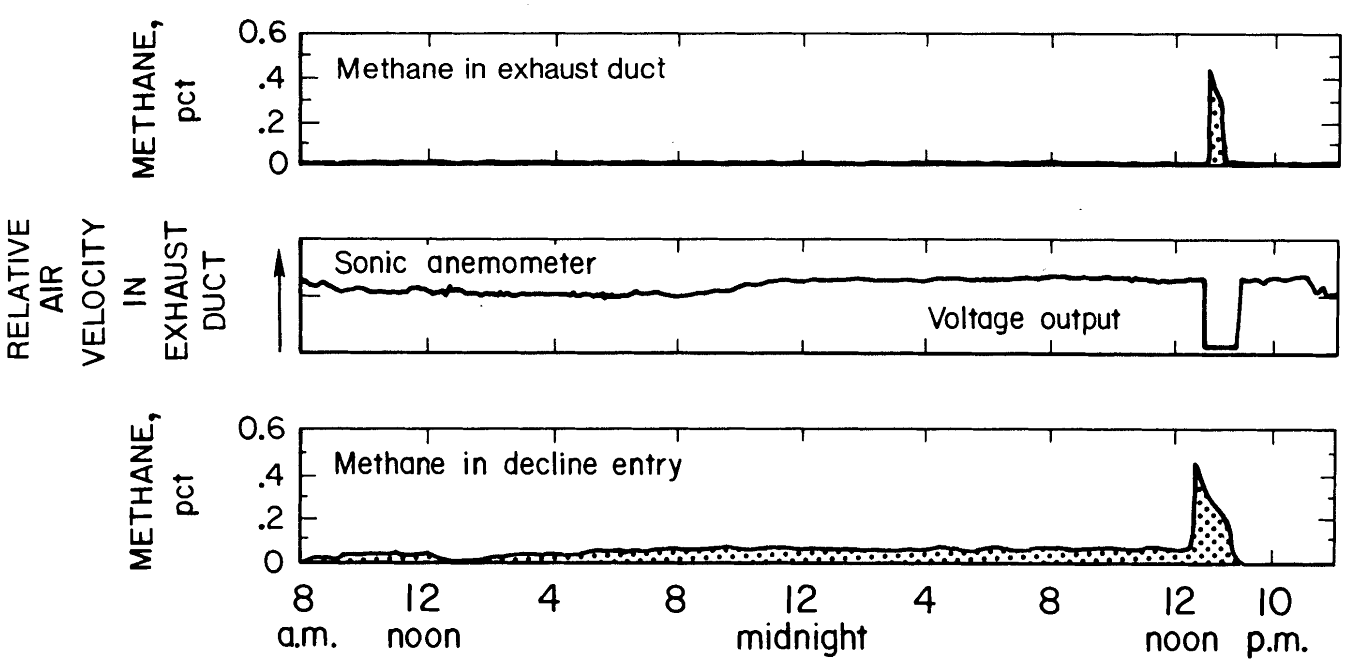

FIGURE 22. - Strip chart recording from a nonproduction weekend.

was emitting methane that was being transported up the decline along the roof. The spike of methane from both sensors at approximately 12 p.m. (July 26, fig. 22) occurred because of a power outtage, which cut off the ventilation fans and allowed natural ventilation to develop. During this period of natural ventilation, there was a small build up of approximately 0.45 pct methane throughout the methane-monitoring area. When the fan was turned on again, methane concentrations dropped rapidly to zero. A similar small build up of methane was observed when a fan was not in operation on June 2 (fig. 23). The maximum concentration of methane measured during this period was approximately 0.17 pct.

The data collected after July are offered only as observations because of the complication to the ventilation system.

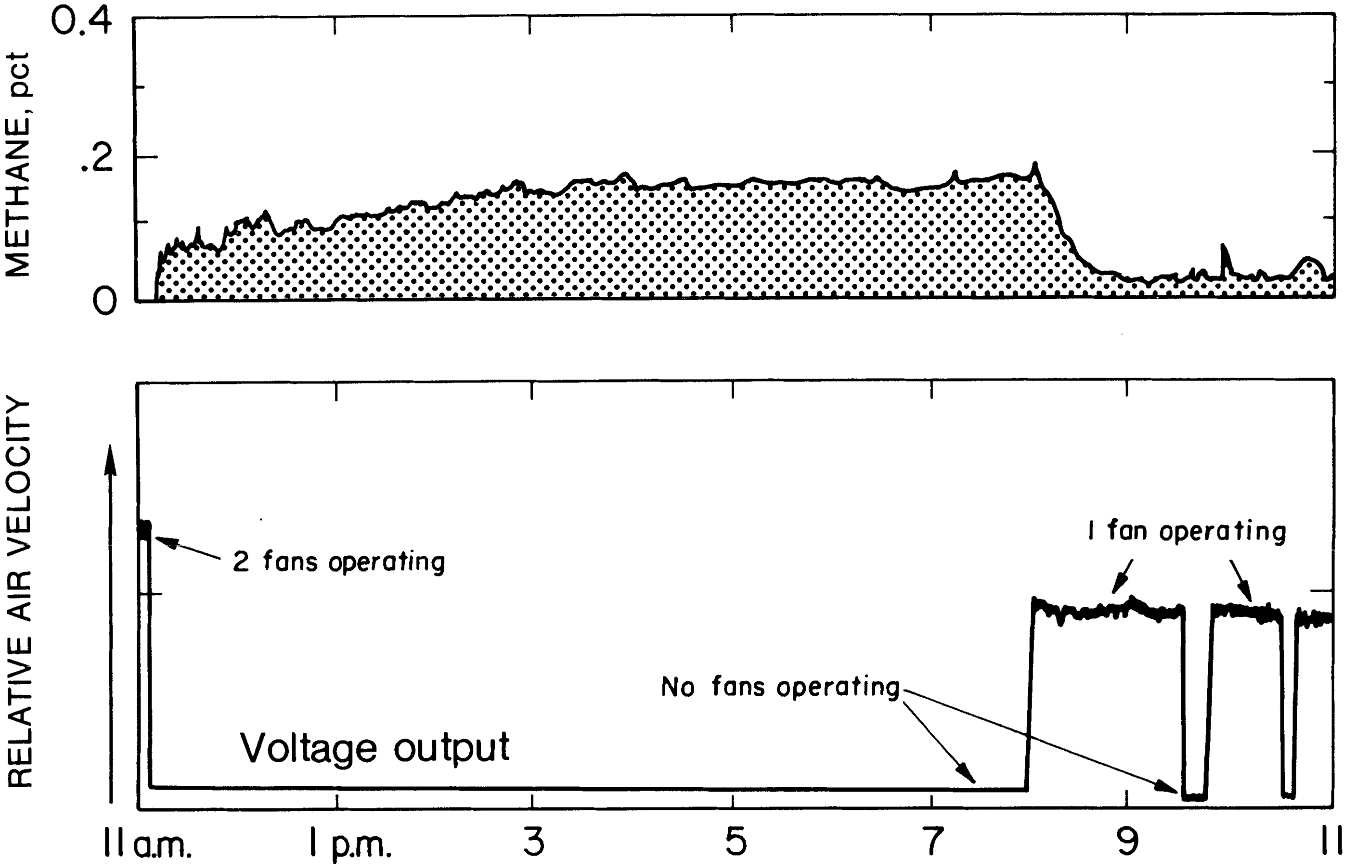

FIGURE 23. - Strip chart recording of methane concentration measured at relative air velocities within exhaust duct.

However, rib emissions probably occurred because of the permeability of the salt from this anomalous zone. It should also be pointed out that even without forced ventilation, methane emitted from the rib did not raise the concentrations in the entry above one-half of a percent.

EXPLORATORY DRILLING INTO ANOMALOUS ZONE

To further investigate some of the physical characteristics associated with the area of high emissions, an exploratory drill hole was cored horizontally into the anomalous zone. The drill hole yielded data pertaining to the flows, pressure, and composition of the gas from the salt rock penetrated (fig. 24). Twenty-seven NQ size (diameter of 2.75 in; 45 cm^3) cores from the drill hole were collected to ascertain a description of the physical and compositional characteristics and also to determine the methane content associated with the change from normal to anomalous salt (fig. 25).

Three exploratory drill holes were needed to investigate further the gas characteristics of this anomalous zone. Hole 1 was cored entirely through normal salt (fig. 26). This hole, which represents typical salt from a normal nongassy face, was cored approximately 154 ft (47 m) at a bearing of 293° and an angle of 0.25° above the horizontal from the face of room F. Methane flows were zero except when pumping the inner core barrel down the hole. Even then, the methane concentration of the gases exiting the drill hole reached only 0.1 pct (the remaining 99.9 pct consisted of air). No other flows were measurable during the drilling of hole 1. Upon completion of

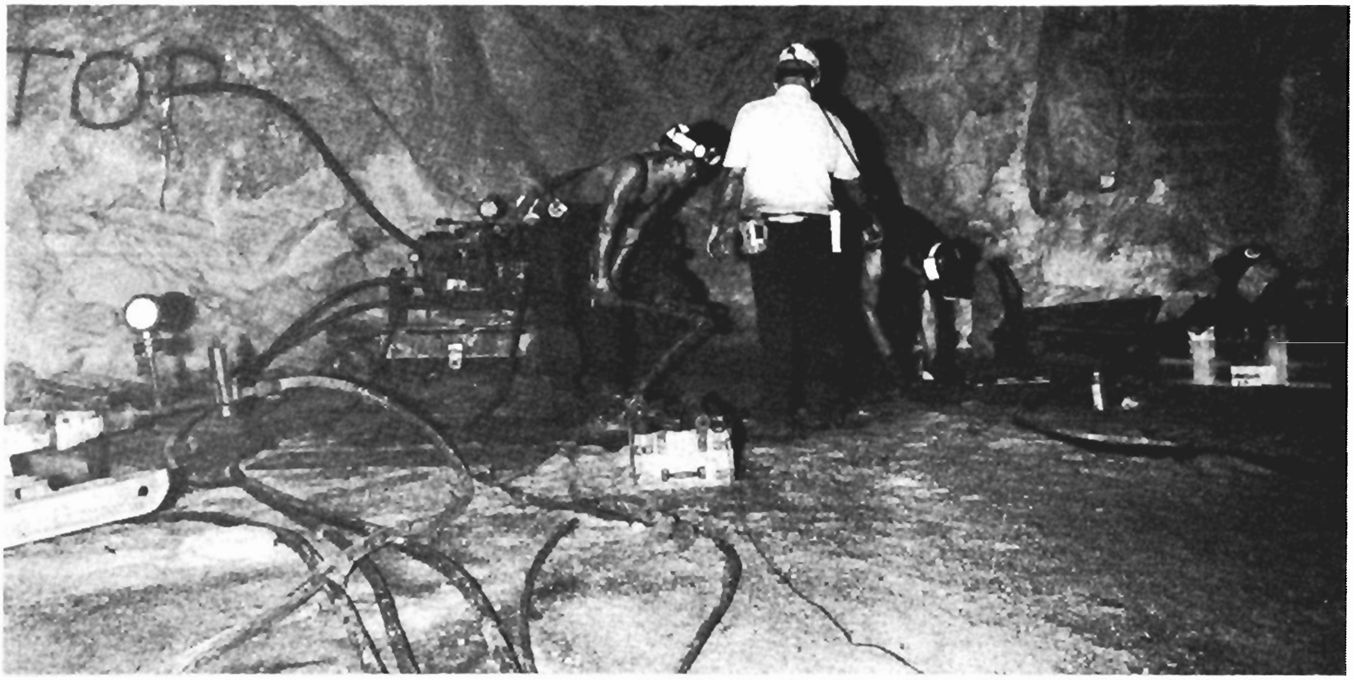

FIGURE 24. - Equipment assembly for exploratory drilling in study area.

FIGURE 25. - Salt core recovered from exploratory drill holes. Cores were physically inspected and bagged for methane content test.

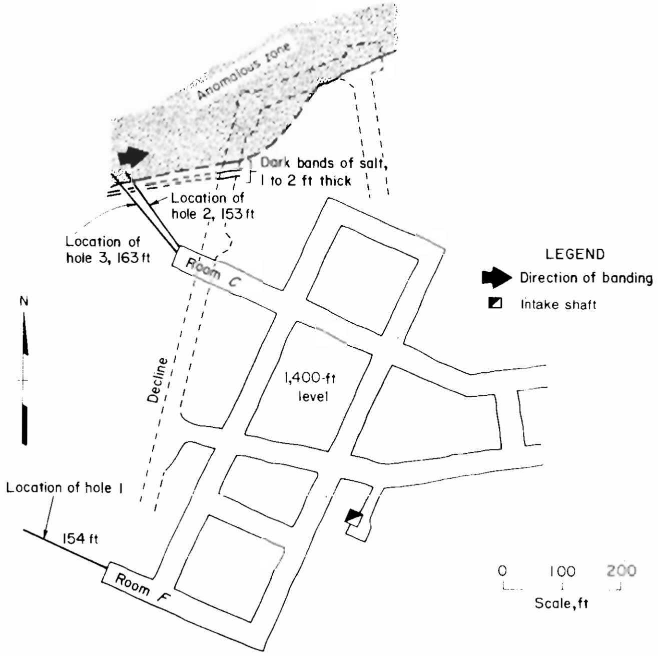

FIGURE 26. - Location of three exploratory drill holes on 1,400-ft level and their position relative to anomalous zone.

drilling, the hole was shut-in for approximately 20 h. During this time, no pressure buildup was observed within the hole. Methane contents of the cores were also consistently low (table 2).

Hole 2 was drilled from an area of normal nongassy salt into the edge of the anomalous gassy salt. The hole was drilled approximately 131 ft (40 m) at a bearing of 325° and an angle of 7° above

TABLE 2. - Average CH_4 contents of cores from normal salt and transitional zone, and rib samples from the anomalous zone

Salt type or source	Number of samples	Rel. conc. of CH_4	Mean ($\bar{x}$), ft^3/ton (cm^3/100 g)	Std. dev. (σ), ft^3/ton (cm^3/100 g)
Normal.............	23	1	0.0015 (0.0046)	0.0011 (0.0034)
Transitional zone[1].	4	4	.0066 (.0206)	.0047 (.0146)
Anomalous zone.....	5	220	.3304 (1.0324)	.3656 (1.1424)

[1] Dark bands adjacent to anomalous zone.

TABLE 3. - Gas analysis from drill hole 2, percent

Time after encountering anomalous zones, h	$O_2 + N_2$	Ar	CO_2	CO	CH_4	CH[1]	Location of sample
<1.................	1.95	0.02	4.78	0.0	93.01	0.24	4 in (10 cm) inside end of drill pipe.
	1.92	.02	4.75	.0	93.08	.23	Do.
	1.91	.02	4.77	.0	93.03	.25	Do.
3.................	1.89	.02	4.80	.0	93.05	.24	Exhaust from drill hole after pressure test.
18.................	1.87	.02	4.75	.0	93.07	.24	Do.
	[2]40.11	.38	2.45	.0	56.91	.15	4 in (10 cm) inside end of drill pipe.
	[2]61.98	.58	1.81	.0	35.52	.10	Do.

[1] Other hydrocarbons.

[2] Flow rate dropped to near zero. Air from entry began contaminating drill hole.

the horizontal plane from the face of room C (fig. 26). Methane emissions were zero from the first 120 ft (37 m) of the drill hole. The core from the first 120 ft (37 m) was found to be typical of the normal salt found in the study area. At approximately 125 ft (38 m), a distinctive odor signaled the penetration into a gassy zone of salt. This odor was later attributed to the presence of a small concentration of mercaptans. Drilling was interrupted after approximately 5 ft (1.5 m) more of penetration so that gas concentrations and flows could be measured. Methane concentrations of over 90 pct were found with a methanometer and later confirmed by gas chromatographic analysis (table 3).

Approximately 4 h after penetration, a gas flow of 42 ft^3/h (1.2 m^3/h) was measured. One hour later, the flows dropped to near zero [4 ft^3/h (0.1 m^3/h)]; however, methane concentrations remained above 90 pct. Conditions were such that only two observations of flow could be made (fig. 27). Approximately 500 ft^3 (14.2 m^3) of methane was estimated to

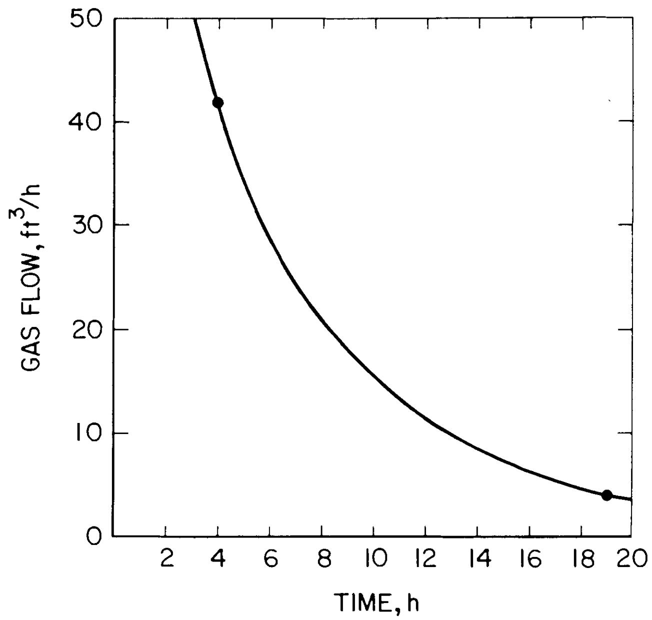

FIGURE 27. - Gas flow from hole 2.

have been emitted from this hole 20 h after encountering the gas flow. This total flow is significantly less than that of another exploration hole drilled by the mine operator which had a total flow of 39,000 to 49,000 ft^3 (1,104 to 1,388 m^3) of methane. The hole was drilled from the decline face to a depth of approximately 150 ft (46 m) within this anomalous zone (14).

Close examination of the salt core showed a change in the lithology of the salt where penetration of the gassy zone occurred. Two dark bands of salt, 1 to 2 ft (0.3 to 0.6 m) thick, were observed to occupy the interval from which gas emissions were first encountered. These dark bands are similar to those observed directly adjacent to the dark argillaceous salt of the anomalous zone approximately 168 ft (51 m) away in the decline (fig. 26). The drill hole had just begun to encounter the anomalous zone, and the bands represent a transitional zone between normal and anomalous salt. Core samples from the dark bands adjacent to the anomalous zone had an increase in methane content by a factor of 4 when compared to that of normal salt. Rib samples collected from the anomalous zone were approximately 220 times higher in methane content (table 2).

Hole 2 was extended from 131 ft (40 m) to 153 ft (47 m) 9 months after the initial coring. In addition, a third hole was rotary drilled 163 ft (50 m) at a bearing of 320° and an inclination of 3° (fig. 26). In situ gas pressures were

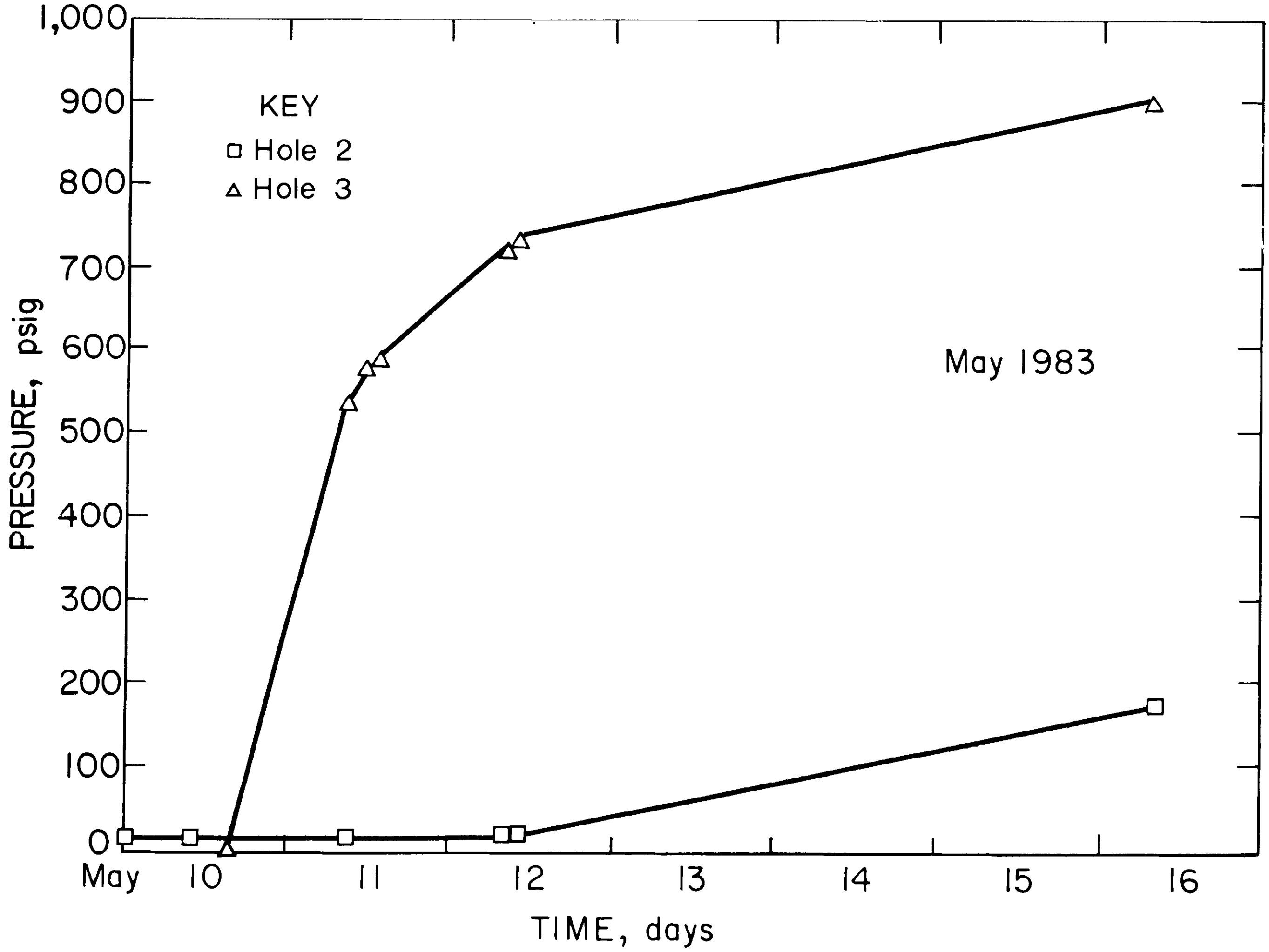

FIGURE 28. - Gas-pressure buildup in holes 2 and 3 after encountering anomalous zone.

measured in both holes by packing the portions of the hole located in the anomalous zone. Gas pressures in hole 3 rose to 903 psig (6,226 kPa) in a 6-day period (fig. 28). However, in hole 2, which had been partially drilled prior to hole 3, pressure did not exceed 10 psig (69 kPa) until the pressure in hole 3 exceeded 700 psig (4,830 kPa). At this point, hole 2 began to build up pressure over a 4-day period, reaching approximately 175 psig (1,210 kPa). These two holes were 24 ft (7 m) apart at their end points.

Information from the three drill holes, along with the other data previously discussed in this report, indicates that the normal salt adjacent to the anomalous zone presents a less significant methane hazard than does the anomalous zone itself. It appears that higher methane emission rates are a result of localized permeability, increased methane contents, and excessive gas pressure of the salt within this anomalous zone. These characteristics will also increase the potential for other methane hazards such as outburst. This implies the need for special control technologies for mining through a gassy anomalous zone such as that found in the study area.

DISCUSSIONS OF POTENTIAL METHANE CONTROL STRATEGIES

A possible methane control strategy would include identification, delineation, and orientation of the gassy anomalous zone; determination of the degree of severity of this potential hazard; development of special mine-through techniques and procedures; and, if it is believed the hazard may be too great, how to avoid the zone.

IDENTIFICATION, DELINEATION, AND ORIENTATION OF A GASSY ANOMALOUS ZONE

Before a methane control plan can be formulated, the potential problem area must be identified. The identification of a gassy anomalous zone can be accomplished by geologic in-mine mapping investigations and an explorational drilling program.

Geologic in-mine mapping should include an inspection and description of salt types with emphasis on the presence of brine or gas seeps, fluid or gaseous inclusions, grain size, striations, orientation of banding, and location and geometry of outburst. Once the mine has been sufficiently mapped, trends of anomalous zones of salt can be established for the entire mine. This will allow for projections of anomalous zones into unmined portions of the salt dome close to the working sections. Also, because the domal salt is often nearly vertically bedded, projections of these trends can be made into superjacent and subjacent mining levels.

Exploratory drilling confirms projections made from in-mine mapping near the working face areas. Core drilling is recommended for providing the most reliable information, but examination and testing of cuttings from rotary drilling can supply some useful information. Because of the great difficulty and potential hazards associated with drilling into salt domes from the surface, this exploration program should be conducted from within the mine. The length and number of exploratory drill holes needed to successfully identify an anomalous zone cannot yet be established. Some mines have established procedures of drilling several 100- to 300-ft (30- to 90-m) holes from every face developing in unmined regions of the dome. The number and lengths of these holes should be dependent upon both projected conditions from in-mine mapping and results of initial drilling from that particular face.

DETERMINING THE SEVERITY OF THE POTENTIAL HAZARD

Several combined techniques could be used to determine the degree of severity to be expected when mining through a projected gassy anomalous zone. Accurate records of gas emission problems encountered during development of the face should be routinely collected. Detailed physical property tests related to gas of an anticipated anomalous zone with exploratory drilling that incorporates the dissolution techniques developed by Hyman (15) will aid in evaluating the severity of the potential methane hazard. Although conditions within the anomalous zone may change rapidly (permeability, pressure, methane content, etc.), previous mine-through data could be used to confirm results developed from these tests conducted during exploratory drilling.

Physical properties tests from explorational drill holes provide generalized gas flow and gas pressure data of projected anomalous zone so that a comparison could be made with other anomalous zones and with normal production-grade nongassy salt. Additional test concerned with the permeability of the zone could be made to determine its effect on the flow and pressure of the gas. Also, the dominant gas type to be expected when mine-through occurs could be easily determined by gas sampling during drilling.

Methane content analysis of exploration cores will also provide information for comparison with other anomalous zones as well as the normal salt within the mine. To quantify the severity of the hazard, it is hoped that evaluation of a projected anomalous zone can be made with reliable results so that comparisons can be made with other anomalous zones that have been mined-through previously.

SPECIAL MINE-THROUGH PROCEDURES AND TECHNIQUES

After an anomalous zone has been identified in an unmined portion of the salt dome and the degree of the emissions hazard has been.estimated, special mine-through procedures and techniques should be planned. Mining systems to be affected by a control strategy would include (1) selection of equipment (2) mine layout, (3) blasting techniques, (4) area methane monitoring systems, and (5) methane drainage. When selecting equipment for potential methane hazard areas, special attention should be placed on availability and maintenance of permissible equipment at the face areas. A continuous mining system would tend to emit gas steadily into the ventilation system instead of a rapid release like that which may accompany a blasted face. Mine layout should consider the location of these gassy zones so as to minimize their effect on high production areas and maximize the potential for larger quantities of ventilating air currents. Many working faces near a gassy zone would enable the blasting of a potentially hazardous face at a predetermined time, such as the last shift of a work week. If larger emissions did occur, the mine ventilation system would have an entire weekend to render the methane harmless, minimizing production stoppages. Investigations of blasting geometries and techniques may enable the mine operator to advance through a gassy zone with minimal danger of outburst. A sophisticated sensing system could be used to continuously monitor emissions during cutting or blasting. The system would consider and monitor every face as a potential emission problem. If the gassy zone is permeable, drainage holes drilled into high gas pressure areas will reduce the gas pressure locally, lowering the flow rates of methane from the salt into the face area. And finally, if conditions are serious enough, total avoidance of the gassy zone may be desired.

SUMMARY AND CONCLUSIONS

The important characteristics associated with the methane hazard assessment study are as follows:

1. Normal salt adjacent to the anomalous zone studied in this report is considered to present minimal emission problems (<500 ft^3/d, 14 m^3/d).

2. Compared with normal salt, the anomalous zone in the study area presented a much greater gas emission problem (averaging 2,500 ft^3/d; 71 m^3/d).

3. Methane emission rates from the normal salt in the decline area were estimated to contain 0 to 5 ft^3/ton (0.1 m^3/t) of methane.

4. Calculations of methane emission rates from the anomalous zone in the decline ranged from 10 to 70 ft^3/ton (0.3 to 1.8 m^3/t) and averaged approximately 27.3 ft^3/ton (0.7 m^3/t) over a span of 47 production days.

5. Emissions occurred mainly during or shortly after production from advancing faces.

6. Rib emissions did occur in the anomalous zone, but they were generally far less significant than face emissions.

7. Emission rates can vary by as much as a factor of 2, depending upon the angle of face advancement to banding in an anomalous zone.

8. Comparison of emission rates with methane contents from the decline anomalous zone show the methane contents of the salt to be 83 times smaller than the emission data.

9. Pressure and flow of gas within the normal salt adjacent to the anomalous zone encountered in the explorational drilling were extremely low.

10. Pressures and flow properties of gas increased dramatically within the anomalous zone. Gas flow of approximately 42 ft^3/h (1.2 m^3/h) and gas pressures of approximately 900 psig (6,200 kPa) were measured when exploratory drilling encountered the anomalous salt.

Assumptions developed from this investigation are as follows:

1. Compared with normal salt, anomalous zones may represent a higher potential methane emission hazard. This is substantiated by previous information from various studies of anomalous features of Gulf Coast salt mines and by this study at the Belle Isle Mine.

2. The anomalous zone is permeable when compared with the generally impermeable nature of the adjacent normal salt.

3. Permeability variations may depend on the orientation of banding and fracture planes within an anomalous zone.

If the characteristics of the anomalous zone investigated in this study are similar to those of other anomalous zones within the Gulf Coast Salt Domes, and if the ideas developed herein are valid, the following conclusions can be drawn:

1. Anomalous zones can be observed, mapped, and projected within limited regions around working sections of underground domal salt mines.

2. Explorational drilling will aid in further identification of these anomalous zones away from the working sections. Orientation and projection of anomalous zones can be defined from trends of banding observed in salt cores.

3. Data from past mine-throughs and physical property tests related to gas of an approaching anomalous zone will aid in determining the severity of the potential hazard and will assist in developing an effective strategy for controlling methane hazards in Gulf Coast salt mines.

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U.S. GPO: 1984-705-020/5020

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