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Investigation of Similarities Between Methane Drainage Potential of Utah's Sunnyside Coalbed and Eastern U.S. Coalbeds

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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Btu/ft^3	British thermal unit per cubic foot
cm	centimeter
cm^3/g	cubic centimeter per gram
ft	foot
ft^3	cubic foot
ft^3/d	cubic foot per day
$(ft^3/d)/ft$	cubic foot per day per foot
ft^3/min	cubic foot per minute
ft^3/st	cubic foot per short ton
h	hour
in	inch
in/min	inch per minute
lb/in^2	pound (force) per square inch
lb/in^2 g	pound (force) per square inch, gauge
m	meter
min	minute
pct	percent

INVESTIGATION OF SIMILARITIES BETWEEN METHANE DRAINAGE POTENTIAL OF UTAH'S SUNNYSIDE COALBED AND EASTERN U.S. COALBEDS

By Gregory M. Molinda,[1] Thomas M. Kohler,[2] and Gerald L. Finfinger[3]

ABSTRACT

The Bureau of Mines has completed an investigation of the effectiveness of methane drainage in the Lower Sunnyside Coalbed at Kaiser Steel Corp.'s Sunnyside No. 1 Mine in Utah. Most of the previous attempts to drain methane gas using long horizontal holes were conducted in the Eastern Coal Province. From the high degree of success realized in these efforts and the large body of knowledge gained from associated research, it seemed natural to extend the technology to western coalfields.

Previous work had indicated that properties affecting gas drainage were variable in the Sunnyside Coalbed. In an attempt to characterize these properties, four degasification holes were drilled from the outside entries of an advancing section. The holes were drilled to lengths of 780, 1,680, 1,315, and 1,047 ft and produced initial flow rates of 50,000, 180,000, 340,000, and 240,000 ft^3/d, respectively. A total of over 300 million ft^3 of commercial-quality gas has been removed from the Sunnyside Coalbed. The four holes have reduced face emissions by 78 pct.

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INTRODUCTION

The Bureau of Mines began investigating methods of controlling gas emissions into underground mine workings in 1964. Since that time, a number of successful projects in the Pittsburgh Coalbed have shown that horizontal gas drainage holes can reduce methane gas emissions by as much as 70 pct (1).[4]

In the present investigation, the Book Cliffs coalfield in east-central Utah (fig. 1) was selected for several reasons. First, the coalbeds in this area closely approximate eastern coals in rank and gas content. Second, the strata are structurally simple with flat-lying beds. Third, the Sunnyside Coalbed presented some unique gas reservoir conditions.

Mines in the Book Cliffs coalfield have historically been hazardous workplaces. Bumps or small outbursts, which are rare in Eastern U.S. coalbeds, are common in the Book Cliffs coalfield. The coal in the area of Sunnyside Mines is highly stressed and tends to fail violently. Several major mine explosions have been related to sudden releases of gas during face and rib failure (2). Like the eastern mines, the Sunnyside Mines experience persistent methane emissions at the face. All these characteristics made the Sunnyside Mines an excellent site for the study of gas drainage properties.

Gas emissions in a particular coal mine depend primarily on the permeability, gas content, and gas pressure of the coalbed. Estimated permeability, gas content, and gas pressure of the Sunnyside Coalbed are 2 millidarcies, 160 ft^3/st, and 620 lb/in^2, respectively (3). These are approximate figures, subject to wide variation, depending on location.

Because there are some differences in characteristics of the Sunnyside Coalbed and those of coalbeds in the Eastern United States, the effectiveness of horizontal holes for methane control in the Sunnyside Coalbed could only be determined by in-mine trials. The purpose of the present study was to plan, implement, monitor, and evaluate a methane control strategy using horizontal holes in the Sunnyside Coalbed and to compare the reults with methane control results from studies in the Eastern United States.

ACKNOWLEDGMENTS

The cooperation of Kaiser Steel Corp.'s Sunnyside Mines, Sunnyside, UT, has been greatly appreciated. Special thanks go to Bret Harvey, mine manager, and Bart Hyita, mining engineer, for their encouragement and assistance in completing the methane control study at Manshaft Dips.

PREVIOUS STUDIES AT SUNNYSIDE MINES

Previous studies had indicated the need to characterize the gas drainage properties of the Sunnyside Coalbed, where the coal characteristics are conducive to high stress buildup. The coalbed (both upper and lower splits) is hard, brittle, relatively unfractured, and exhibits poor cleat development. These characteristics undoubtedly influence coalbed permeability, and thus gas drainage.

Perry (1) reported drastic variations in drill bit penetration rates encountered in a previous horizontal methane drainage project at the Sunnyside No. 1 Mine. Drill bit penetration rates varied between 6 and 36 in/min, in holes drilled in the same direction and separated by only 350 ft (fig. 2). Variable penetration rates from 6 to 18 in/min were noted while drilling the four drainage holes for the present study. Hargrove grindability tests performed on coal samples collected during drilling indicated that coal hardness remained constant. The observed variability in penetration rates was indicative of rapidly changing stress fields, possibly related to mining, which could affect permeability and thus drainage effectiveness. Changing stress fields could also

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

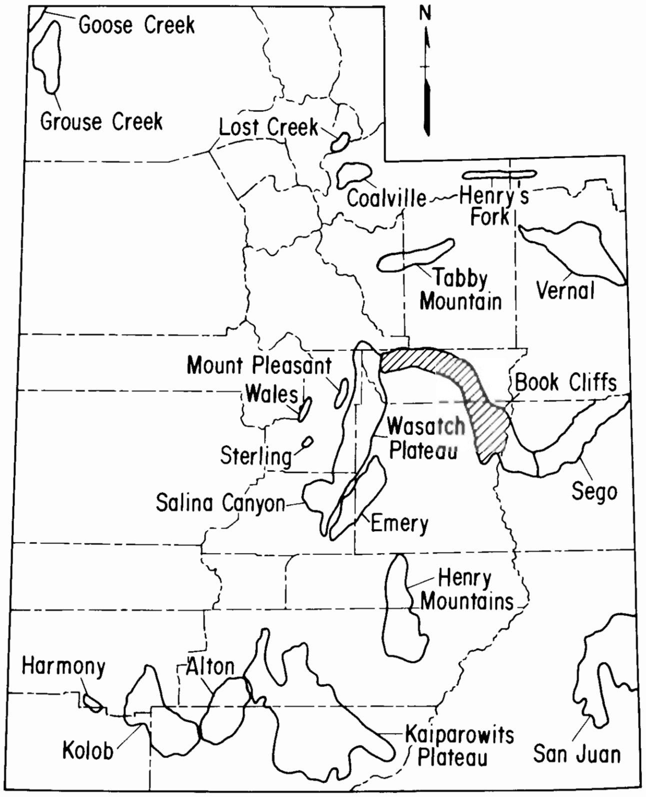

FIGURE 1. - Location of Book Cliffs and other Utah coalfields.

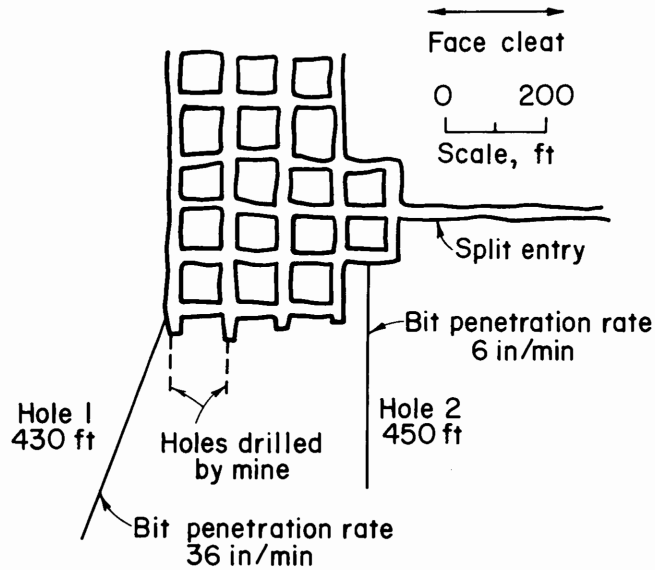

FIGURE 2. - Map view of previous methane drainage holes at Sunnyside Mine No. 1, Manshaft Dips section.

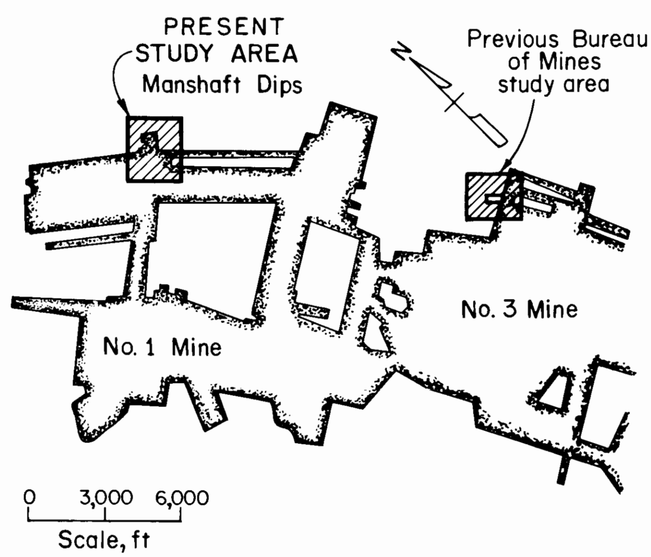

FIGURE 3. - Outline of Sunnyside Mines showing locations of past and present study areas.

be caused by rapidly changing local relief, which greatly exceeds the local relief over most Eastern U.S. coalbeds.

Another indication of variable reservoir conditions was seen in a previous Bureau drilling project. Drainage holes drilled in the No. 1 and No. 3 Mines (fig. 3) showed large differences in productivity. This could have been due to several factors, including variable gas content, bleedoff of gas due to adjacent mine workings, hole direction, hole blockage, variable stress fields, or physical properties of the seam and coal, such as variable permeability.

In this earlier degasification project, face emissions in the No. 3 Mine were roughly one-eighth those in the No. 1 Mine (Manshaft Dips section), even though the No. 3 Mine is under deeper cover (1,800 ft versus 1,200 ft). Gas drainage holes in the two mines also showed different initial production. Short drainage holes from the No. 3 Mine (180 and 85 ft long) showed negligible production, while one hole (95 ft long) from the Manshaft Dips section of the No. 1 Mine was producing 50,000 ft^3/d. This possibly indicated the superior reservoir qualities of the Manshaft Dips area, as opposed to the No. 3 Mine study area.

In a later study at the No. 1 Mine, Manshaft Dips section, two degasification holes, one drilled at 20° off face cleat direction (430 ft long) and one drilled perpendicular to face cleat (450 ft long) (fig. 2), produced 160,000 and 127,000 ft^3/d, respectively. These two holes were on production 9 months and produced over 35 million ft^3 of methane. The reasons for the extreme disparities in gas production from drainage holes in the No. 1 and No. 3 Mines are not known.

STUDY AREA

The methane drainage site in the Sunnyside No. 1 Mine, Sunnyside, UT, was in the Manshaft Dips section (fig. 3). Prior to the start of this project, the Manshaft Dips section had been closed to mining for 15 months because of excessive methane emissions.

The methane drainage plan was to complete four horizontal holes from the outside entries of the section. Each horizontal hole was to be drilled to a depth of at least 1,000 ft (305 m). Two holes were drilled perpendicular to face cleat and two holes were drilled parallel to face cleat (fig. 4). The direction of the face cleat is approximately perpendicular to the direction of mining advance of the Manshaft Dips section. The Manshaft Dips section slopes downward at about 5° in the dircetion of section advance.

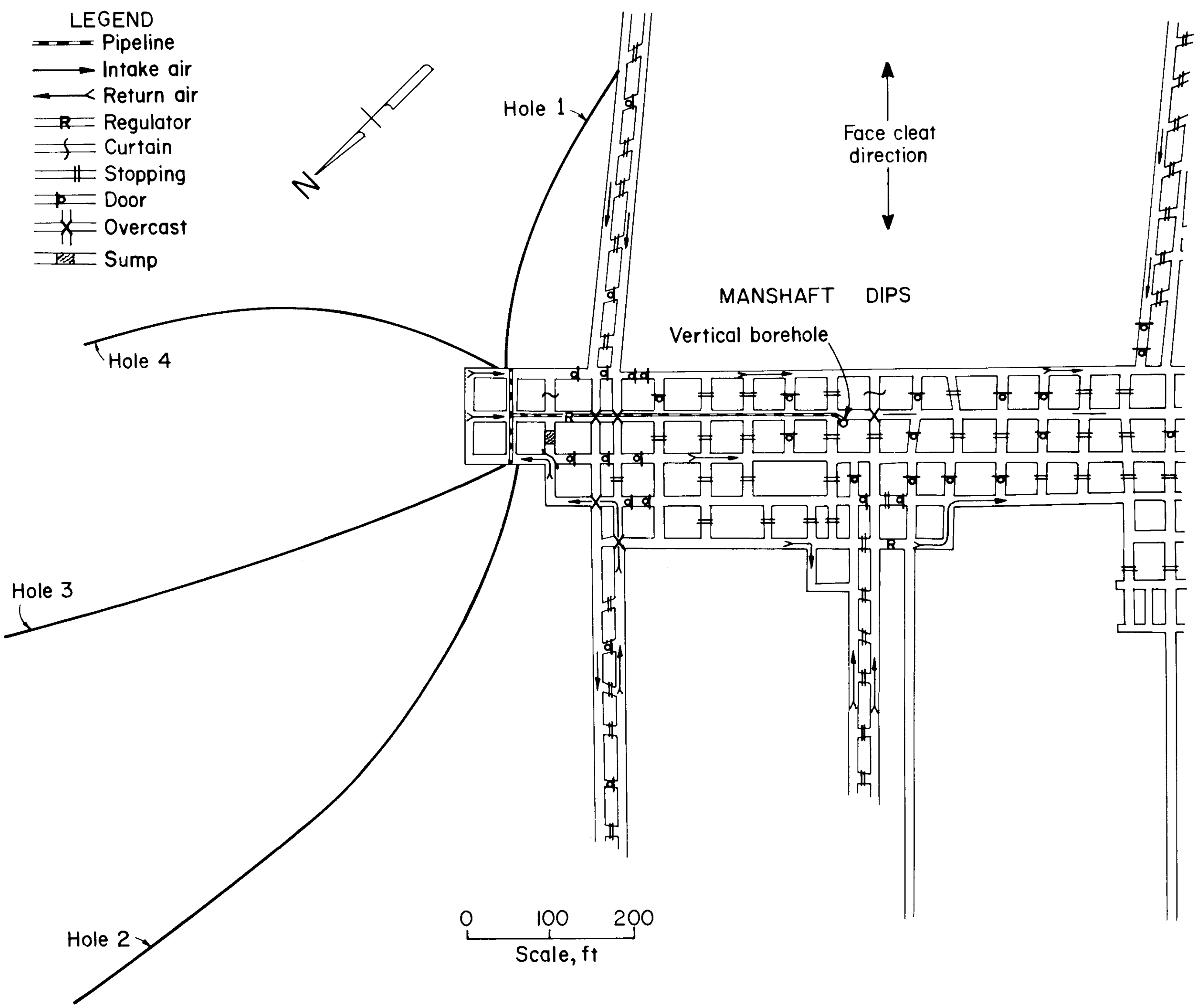

FIGURE 4. - Map view of Manshaft Dips section showing horizontal hole locations.

DRILLING PROCEDURE AND RESULTS

A rotary drilling technique developed by the Bureau in Eastern U.S. coalbeds was also successful in the Sunnyside Coalbed (4). Each hole was drilled with 3.5-in-diam drag or diamond bits powered by an electrohydraulic drill unit. The four holes were drilled to depths of 780, 1,680, 1,315, and 1,047 ft, respectively. (The first hole terminated prematurely when it intersected an entry.)

The results of this drilling project are presented in the next two sections. Subsequent sections discuss physical properties that affect methane drainage potential. Then, general projections are made concerning the potential for future methane drainage from the Sunnyside Coalbed.

GAS FLOWS FROM INDIVIDUAL HOLES

The gas flow from the four horizontal holes was measured by monitoring pressure differentials on 2-in-diam venturi meters and converting the readings to flow rates. Hole production was estimated by collecting a series of spot readings and preparing graphs over the life of the project. Gas flows between readings were assumed to be at levels determined by drawing a straight line between consecutive readings. This same procedure had been used successfully in the Eastern U.S. coalbeds. The gas production data in table 1 are based on the assumption that production from the horizontal holes was uninterrupted between the spot readings.

Table 1 gives the initial, stabilized, and total production, as well as the production life for each of the horizontal holes. Initial flows from holes 3 and 4 were considerably higher than those from holes 1 and 2. This was to be expected, since holes 3 and 4 were drilled perpendicular to the face cleat, whereas holes 1 and 2 were more or less parallel to the face cleat (fig. 4). The greatest production can be expected from holes drilled perpendicular to the direction of the face cleat, since holes so oriented are most likely to intersect face cleats, which can conduct methane gas. Also, hole 1 was inadvertently drilled into a set of bleeder entries and had a low flow rate because of its relatively small drainage area. To understand the importance of cleat direction with respect to gas production in the Sunnyside Coalbed, hole depth must also be considered. Using the hole depth, the gas flow per linear foot of horizontal hole can be determined.

Holes 1 and 2 (parallel to the face cleat) had initial gas flows of 64 and 107 $(ft^3/d)/ft$, respectively. Holes 3 and 4 (perpendicular to the face cleat) had initial gas flows of 258 and 229 $(ft^3/d)/ft$, respectively. Thus, face cleat direction was determined to be an important consideration in planning a horizontal methane drainage program in the Sunnyside Coalbed, as had also been the case in the Eastern U.S. coalbeds.

Figure 5 shows the gas production from the individual holes thoughout the life of the project. The general shape of the curves is similar to that of production curves from horizontal methane drainage holes drilled in Eastern U.S. coalbeds. The constituents of the coalbed gas drained from the horizontal holes are shown in table 2. The gas from the Sunnyside Coalbed was comparable to selected

TABLE 1. - Gas production data for the four horizontal holes

Hole	Production, 10^3 ft^3/d		Production life, days	Total production, 10^6 ft^3
	Initial	Stabilized		
1........	50	10	640	5.4
2........	180	120	670	82.0
3........	340	200	700	145.0
4........	240	110	600	69.0

Eastern U.S. coalbed gases, and was suitable for commercial utilization. However, since no commercial gas pipeline was available, the gas was vented to the atmosphere.

OVERALL REDUCTION OF METHANE EMISSIONS

One objective of the methane drainage study at the Sunnyside No. 1 Mine was to reduce the amount of methane being emitted into the Manshaft Dips section. Ventilation surveys of the section were conducted before and after drilling to determine the quantity of methane entering the section. Air velocities were measured with vane-type anemometers, and methane levels were determined in the laboratory from bottle samples.

The total volume of methane emitted in the Manshaft Dips section prior to horizontal drilling was 248 ft^3/min. At the completion of the drilling study, methane emissions in the section had decreased to about 60 ft^3/min, showing that the horizontal holes were capturing about 188 ft^3/min, or approximately 78 pct of the predrilling emissions. By comparison, degasification had reduced methane emissions by up to 70 pct in Eastern U.S. coalbeds by degasification (5).

Figure 6 shows the methane levels before and after drilling, as well as the effect on methane levels of interrupting production from the horizontal holes. When the holes were shut down, methane emissions in the Manshaft Dips section returned to about the predrilling level. In the three holes that were deeper than 1,000 ft, methane that was trapped beyond 1,000 ft was allowed to flow through the

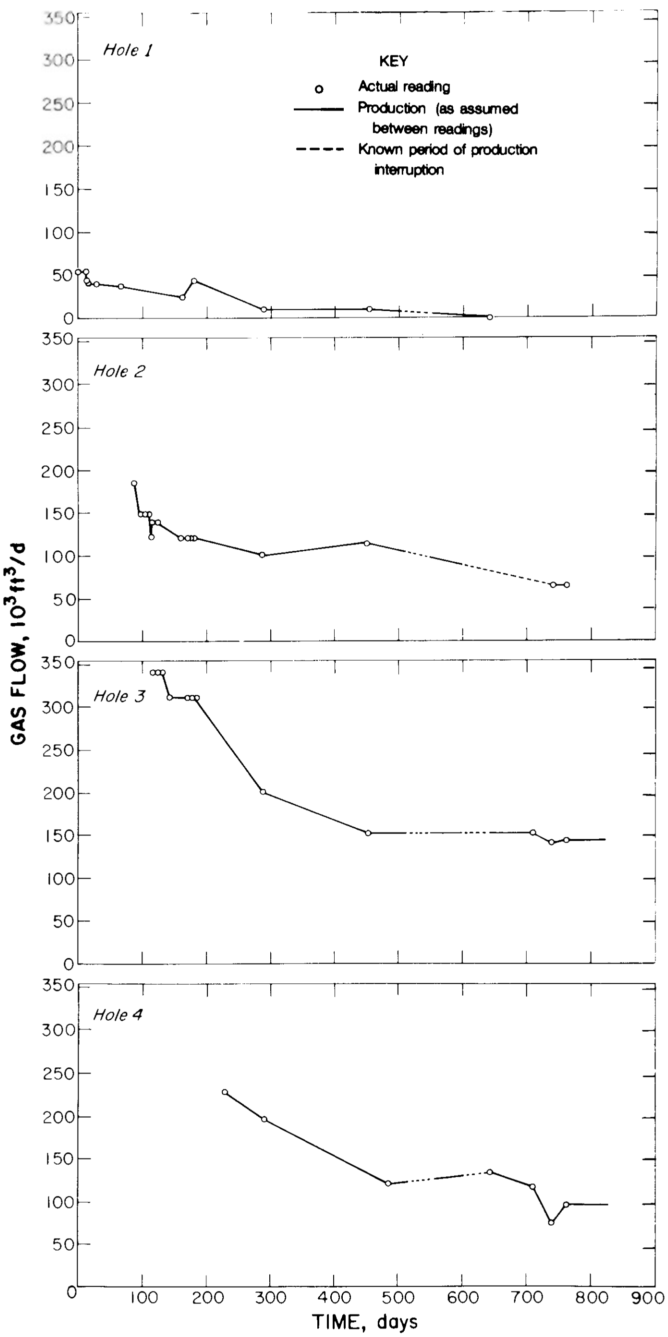

FIGURE 5. - Gas production from horizontal holes at Manshaft Dips section.

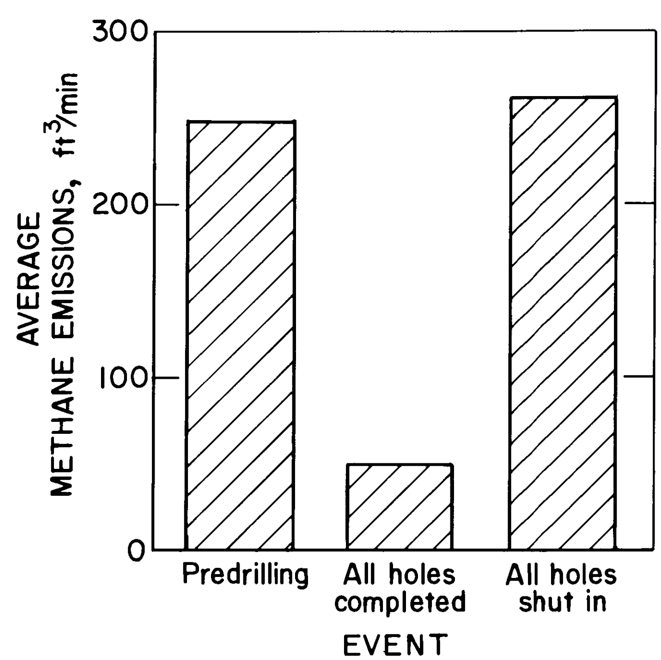

FIGURE 6. - Methane emissions during key events at Manshaft Dips section.

TABLE 2. - Comparison of constituents of coalbed gas from selected coalbeds, percent

	Sunnyside	Pittsburgh	Pocahontas No. 3	Kittanning
Methane (CH_4)	97.13	95.86	97.07	95.47
Ethane (C_2H_6)	.0304	1.08	1.25	ND
Propane (C_3H_8)	.0008	ND	.0011	ND
Butane (C_4H_{10})	.0003	ND	.0001	ND
Carbon dioxide (CO_2)	1.69	2.54	.20	.10
Nitrogen (N_2)	.78	.46	2.79	3.97
Oxygen (O_2)	.38	.06	.16	.47
Btu/ft^3	984	989	1,005	966

ND Not detected.

borehole to the valve without restriction. With a minimal pressure, methane bypassed the shut-in valve by flowing through the natural fracture system (cleat) of the coalbed and into the mine workings. However, once the holes were back on production, methane was captured by an underground pipeline and emissions in the section decreased. This emphasizes the importance of maintaining continuous gas production from the holes to ensure that methane concentrations in the section remain at the lowest possible levels.

PHYSICAL PROPERTIES OF SUNNYSIDE COALBED

Several physical properties of coalbeds affect their drainage potential. These include gas content and in-seam permeability.

GAS CONTENT

According to the Utah Geological and Mineral Survey, Book Cliffs gas contents range from 0.0 to 10.0 cm^3/g (6). However, tests performed in this study on the Sunnyside Coalbed were inconclusive because of the small number of data points obtained. Similar tests on the Pittsburgh Coalbed have shown the gas content there to be 6 cm^3/g.

One factor influencing the gas content of coal seams is depth of cover. It has been clearly shown that gas content increases with increasing depth of cover (7). The rugged canyon terrain of eastern Utah, with its deep canyons and rapid relief changes, could explain changes in gas content over short distances.

PERMEABILITY AND GEOLOGY

In general, coalbed permeability appears to depend on several factors, the most important probably being cleat development. Well-developed cleat with good permeability provides effective conduits for transporting gas. Consequently, the most efficient and productive horizontal methane drainage holes are drilled perpendicular to the direction of the face cleat so as to intersect the greatest number of face cleats per unit of hole length. Good cleat development includes well-defined, continuous, open fractures and dense cleat spacing. The upper Sunnyside Coalbed (No. 1 Mine), where the drainage holes were drilled, is characterized by long splintery fractures of rib and pillar that provide excellent permeability despite poor cleat development (8). Theissen and Sprunk (8) reported that the lower Sunnyside Coalbed (No. 3 Mine) has poorly developed cleat. Since it also lacks the long splintery fractures of the upper Sunnyside, the lower Sunnyside exhibits relatively low permeability.

The Utah Geologic and Mineral Survey investigated the possibility of a discontinuity between the No. 1 and No. 3 Mines (6). If the coalbed were interrupted by discontinuity, such as faulting or paleochannel washouts, the gas system could be separated into smaller reservoirs with different properties. Figure 7 is a diagram of the Sunnyside operation in the Book Cliffs, showing both the No. 1 and No. 3 Mines. This diagram shows that the Sunnyside Coalbed persists throughout the two-mine area. Also obvious is the variable nature of the coalbed. Although considered one unit, the coalbed commonly splits into two main benches separated by as much as 75 ft. Usually associated above and below the main benches are two to three thin rider coals.

Schiebner (9) mapped a single-entry longwall development within 1,500 ft of the study area. By drilling coreholes in the roof and floor, several cross sections were constructed which showed the lower bench and associated riders. These coalbeds are within several feet of the actively mined coalbed, and it is known that they contribute methane to the mine atmosphere. Gas has been seen bubbling through standing water at the bottom of an exhaust shaft in the No. 1 Mine (2). Gas is also commonly emitted during roof bolting operations. Other contributors of methane are thick sandstone units in the roof and floor that store gas that has either migrated from coalbeds or has been generated in place by organic inclusions.

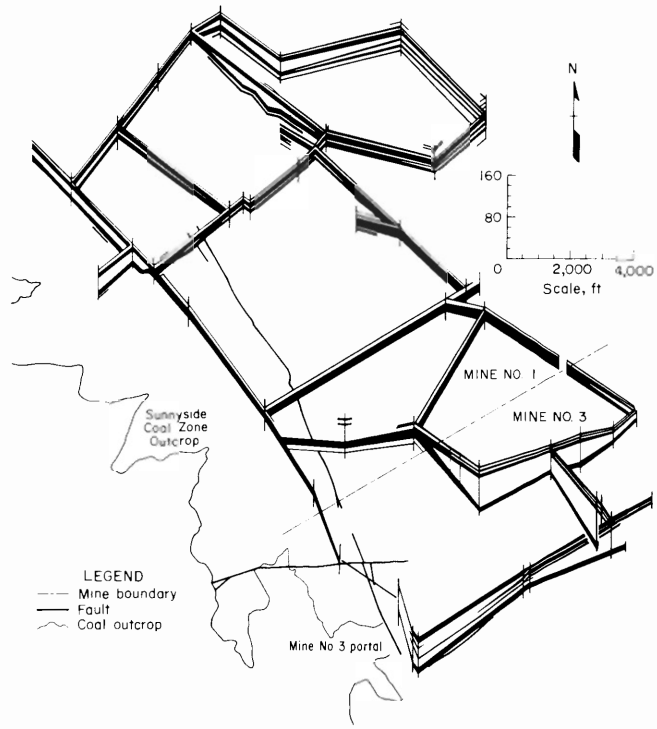

FIGURE 7. - Fence diagram of Sunnyside Coalbed in the Sunnyside No. 1 and No. 3 Mines.

PROJECTIONS FOR POTENTIAL OF FUTURE GAS DRAINAGE AT SUNNYSIDE

Some general statements can be made about reservoir conditions to be anticipated as mining progresses under deeper cover. Gas content should increase due to the increase in confining pressures (which prevents gas escape). Mine emissions should increase due to increased gas content and increased confining pressure. The time needed to degasify coal in advance of mining should also increase. Studies have shown that initial gas flows from deeply buried coalbeds have been lower than initial flows from shallower beds (10) because the greater confining pressures reduce permeability.

Mine emissions will be greatest in the areas where both splits are combined and mined as one seam. Scheibner notes that when both splits are combined they retain their individual characteristics (9), that is, the upper split is fractured and the lower split is not. In drilling drainage holes, it may be advisable to confine drilling to the upper split as much as possible in order to realize optimum drainage.

In evaluating the effectiveness of the four-hole drainage pattern at Sunnyside (fig. 4), it was stated that the drainage holes reduced face emissions by 78 pct. Table 3 gives drainage characteristics for several eastern coalbeds (7). The initial gas flow (per linear foot of hole) from the Sunnyside Coalbed compared favorably with the initial flows from the Pittsburgh, Pocahontas No. 3, and Mary Lee Coalbeds. Although comparison between eastern and western coalfields based on initial flow per foot of hole can be somewhat useful, specific site evaluation is necessary to properly evaluate gas drainage potentials.

TABLE 3. - Comparison of drainage characteristics of selected coalbeds

	Pittsburgh	Pocahontas No. 3	Mary Lee	Sunnyside (upper)
Overburden..........................ft..	500-900	1,600	2,100	1,200
Gas pressure...................lb/in^2..	275	650	830	NA
Gas content....................ft^3/st..	218	430	512	NA
Initial gas flow...........(ft^3/d)/ft..	250	170	200	200

NA Not available.

SUMMARY AND CONCLUSIONS

Horizontal gas drainage holes have been shown to be as effective in reducing excessive methane emissions in Utah's Sunnyside Coalbed as they have been in many Eastern U.S. coalbeds. Four drainage holes with an aggregate length of 4,822 ft produced in excess of 300 million ft^3 of commercial-quality gas from the Manshaft Dips section of the Sunnyside No. 1 Mine. Methane emissions in the section decreased by about 78 pct after the horizontal holes were completed. In previous Bureau studies, methane emissions had never been reduced by more than 70 pct.

Previous studies at the Kaiser Steel Mines in the Sunnyside Coalbed indicated differences in reservoir conditions between the No. 1 and No. 3 Mines. Varying properties such as gas production, drill penetration rate, fracture development, and gas content indicate changing physical properties in the same split of the Sunnyside seam, as well as differences between the upper and lower splits. While both splits exhibit little or no cleat development, the upper split is vertically broken by irregular fractures. This split may have the most potential for development of the coal methane resource. The potential for methane resource development at any particular site depends on physical properties such as gas content, permeability, seam pressure, water saturation, and geologic structure, which all play a role in the final production of gas from a drainage hole.

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