

Investigation of the Gas Content of Coal Seams
in the Vicinity of Charleston, Illinois

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SUMMARY

A preliminary study of the concentration and composition of the gas in coals recovered from a drill hole near Charleston, Illinois, was recently completed by the Illinois State Geological Survey. A continuous core of the rock strata was drilled to a total depth of 1,121 feet. Nine coals were penetrated that were more than 0.5 feet thick. One coal, the Springfield (No. 5) Coal, has a minable thickness of 4.4 feet. Of the nine coals, four were sealed into air-tight canisters and tested for gas content over a three-month period. The Springfield (No. 5) Coal was split into two samples because of a significant difference in the nature of the coal in the upper and the lower portions of the seam.

The results of the testing show the coals have the following gas contents expressed in cubic feet of gas per ton of coal: Shelbyville Coal (?), approximately 8; Danville (No. 7) Coal, 87; Herrin (No. 6) Coal, 44 to 50; and Springfield (No. 5) Coal, upper 1.2 feet, 46, and lower 3.2 feet, 72. The gas contents of these coals are within the range of values determined by previous studies for Illinois coals elsewhere. Compared with some other coal seams in the United States which are characterized by high gas emissions during underground mining, these gas contents are relatively low. Significant differences in the rates at which gas is released from the coals were observed. The Herrin (No. 6) Coal was found to release its gas most readily. An "index of gas productivity" is proposed which may allow easy comparison of different coal samples. Comparison of internal surface area and porosity data to desorption data indicates that porosity and permeability type data do not accurately predict gas contents or gas release rates.

Chemical analyses indicate the coals contain gases having approximately the following composition: methane, 65 percent; other hydrocarbon gases, 10 percent; carbon dioxide, 5 percent; and nitrogen, 20 percent. The gas has a heating value that is about 90 percent of the heating value of normal pipeline gas. The chemical and isotopic compositions of the gases are somewhat different than those of most gases recovered from coals in other areas, but are similar to gases related to petroleum deposits in Illinois. The possibility must be considered that this gas formed elsewhere and migrated into the coals. The chemical and isotopic composition of the gas from the No. 7 Coal is distinctly different from that of the gas from the No. 6 and No. 5 Coals; this suggests that the origin and/or histories of these gases is different.

ACKNOWLEDGMENTS

The Charleston site was made available for drilling through the cooperation of Larry D. Stoever, city planner for the City of Charleston, and Troyt York of the U.S. Department of Energy. The cost of drilling was provided by the Illinois Institute for Natural Resources under contract number 60.047 through the University of Illinois.

We wish to acknowledge the following people at the Illinois State Geological Survey for their assistance: Robert A. Bauer, W. John Nelson and Colin G. Treworgy Coal Section, for assistance in coal collection and core description; Donald J. Lowry, Coal Section, for core preparation; Chao-Li Liu, Analytical Chemistry Section, for performing the isotopic analyses; and Robert R. Frost, Analytical Chemistry Section, for measuring the internal surface areas and porosities of the coals and helping with the evaluation of gas release rates.

INTRODUCTION

This report summarizes the results of a one-hole drilling project in Coles County near Charleston, Illinois. The purpose of the drill hole was to collect cores of coal seams at the site and to measure the natural gas content of the coals. In addition, the investigation has provided information on Pennsylvanian stratigraphy and coal seams, and has enabled us to test our methods and procedures for sampling and analyzing gas from coal.

The amount and composition of gas released from the coal samples is reported here; however, additional study and analysis of the coals is still in progress. The results of that work and a more detailed discussion of the gas data will be reported in an *Illinois Minerals Note* that is now being prepared for publication.

Geology of the study area

The drilling site is located in Coles County about one mile west of the Charleston city limits on land owned and used by the City of Charleston for a sewage treatment plant. Coles County is situated in east-central Illinois (fig. 1) and is bisected by the La Salle Anticlinal Belt, a major geologic structure that accounts for oil and gas production in some areas of Illinois. The drill site is located on the west flank of the La Salle Anticlinal Belt, and strata dip to the west as much as 4° to 5°. The La Salle Anticlinal Belt dies out to the west of the City of Charleston (fig. 2) where the strata in the deep part of the Illinois Basin lie relatively flat.

The study area is underlain by Pennsylvanian strata about 1,500 feet (460 m) thick. Pleistocene glacial deposits up to about 100 feet (30 m) thick overlie the Pennsylvanian strata. The drilling site is within the deeper portion of the Illinois Basin where the Herrin (No. 6) Coal is more than 1,000 feet (300 m) deep.

The subsurface geology and coal resources of this area were studied by Cady (1952) and by Clegg (1959); however, data in those studies were insufficient to permit an estimate of coal reserves. There has been no coal mining at Charleston. The nearest mine is an underground mine at Mattoon (9 miles to the west) in the Danville (No. 7) Coal that was operated from 1883 to 1887. The nearest active mines are in the Herrin (No. 6) Coal in Douglas County approximately 22 miles to the northeast.

The Pennsylvanian strata at Charleston consist mostly of shales and siltstones and occasional limestones and coals. Interpretations of electric logs indicate that four coals are well developed in the area: The Danville (No. 7), the Herrin (No. 6), the Springfield (No. 5), and the Seelyville. The rank of the coals is high-volatile bituminous.

Occurrence of gas in coal

Generally speaking, all coal may contain gases that originate in the coal from the breakdown of organic matter during coalification or that have migrated into the coal from the surrounding rocks. The amount of gas

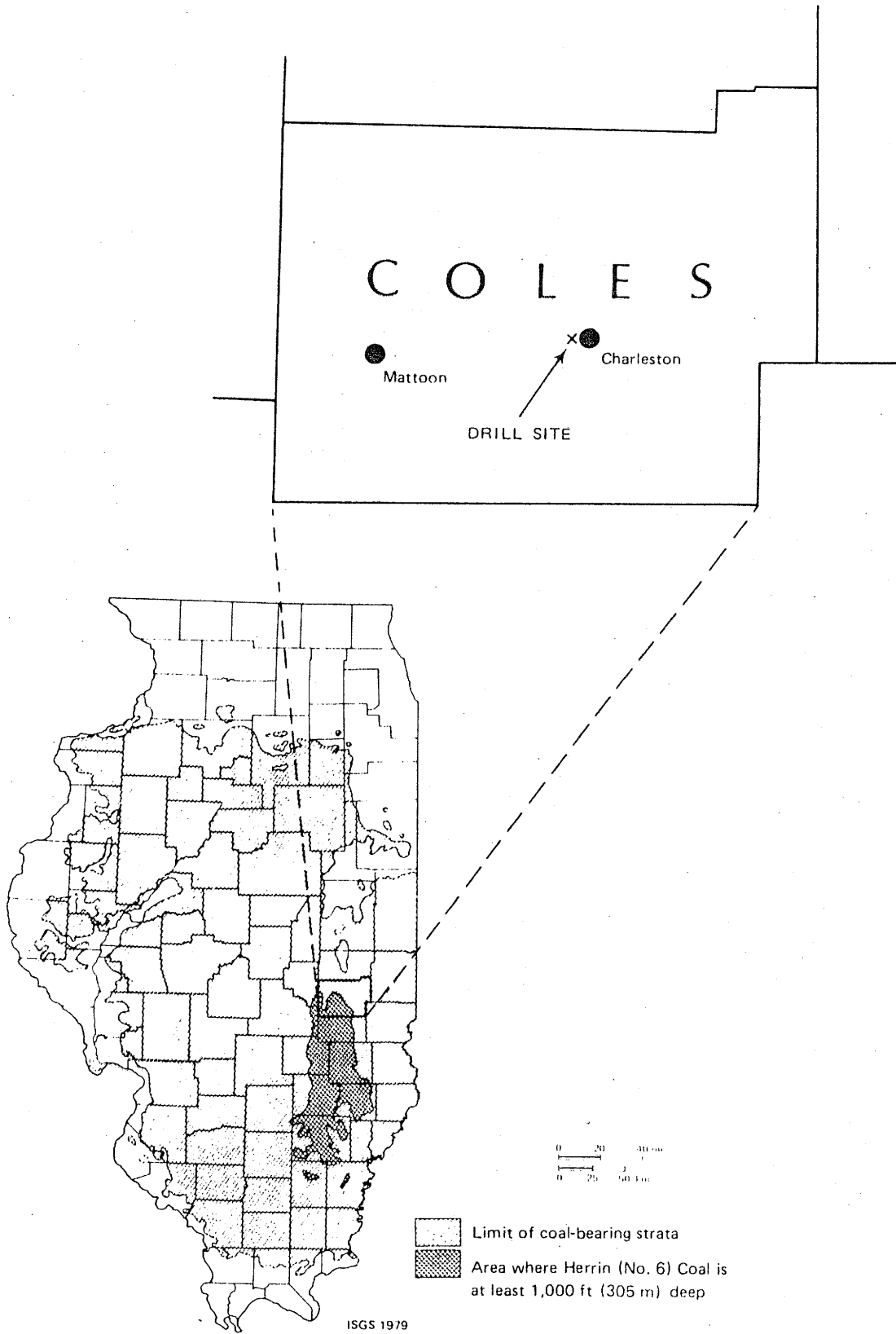


Figure 1. Location of the study area within the Illinois Basin Coal Field.

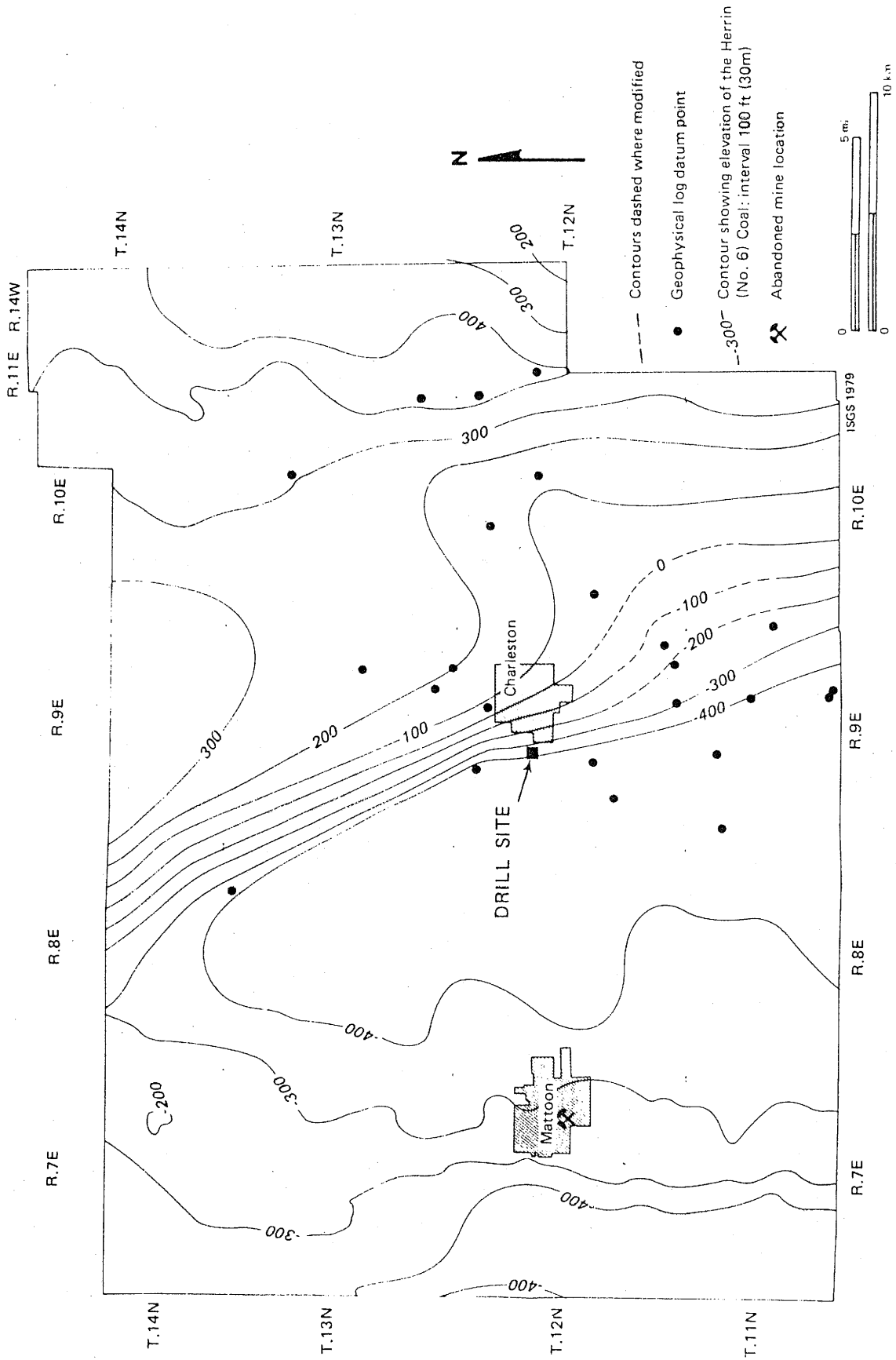


Figure 2. Elevation of the base of the Herrin (No. 6) Coal.

present in coal may be estimated by measuring the volume and pressure of gas desorbed or adsorbed by the coal, or by comparing coals having an unknown gas content to coals of a similar rank having a known gas content. The gas content of coals has been studied for many years in Europe, and some of the European methods have been adapted to coals in the United States by the U.S. Bureau of Mines. The U.S. Bureau of Mines has investigated gas in coals of the United States extensively; references to some of their work are included in appendix A.

Gas in Illinois coal mines has not been a problem of the magnitude of that in eastern U.S. coal fields. Therefore, the gas content of Illinois coals has received little attention in the past; the relatively few measurements that have been made are shown in table 1.

The gas content is not the only factor that determines the feasibility of producing gas from coal. A coal with a relatively low gas content and high permeability could possibly produce more gas than a coal with a relatively high gas content and low permeability. To our knowledge, only one well has produced gas from an Illinois coal; the amount of gas produced from that well was insignificant (Elder and Deul, 1975).

Table 1. Previous measurements of gas content of coals in Illinois

Coal	County	Sample depth (ft)	Gas content	
			cm ³ /g	ft ³ /ton
Danville (No. 7)	Clay ^d	994	< 1.0	< 32.0
Herrin (No. 6)	Clay ^a	1036	< 1.0	< 32
Briar Hill (No. 5A)	Clay ^a	1075	< 1.0	< 32.0
Harrisburg (No. 5)	Clay ^a	1090	< 1.0	< 32
Seelyville	Clay ^a	1352	< 1.0	< 32.0
Herrin (No. 6)	Franklin ^b	n.a.	1.66-2.25	53.1-72.0 ⁺
Harrisburg (No. 5)	Franklin ^b	n.a.	1.2 -2.2	36.4-70.4 ⁺
Herrin (No. 6)	Jefferson ^c	733	1.9	60.8
Harrisburg (No. 5)	Jefferson ^c	793	1.0	32.0
Colchester (No. 2)	Peoria ^d	132.6	1.02	32.6
Herrin (No. 6)	Wayne ^c	902	1.9	60.8
Harrisburg (No. 5)	Wayne ^c	1010	3.1	99.2
Herrin (No. 6)	Wayne ^c	970	3.4	108.8
Harrisburg (No. 5)	Wayne ^c	1070	2.7	86.4

n.a. = not available

+ = numbers represent gas content of more than one coal

Sources: ^aTRW, Inc.
^bU.S. Steel Corporation
^cU.S. Bureau of Mines
^dNorthern Illinois Gas Company

Research goals

The Charleston Drilling Project was undertaken with five primary objectives:

1. To develop procedures and techniques that would allow accurate collection, measurement, and analysis of gas from coals.
2. To determine the amount of gas in the coals near Charleston and to determine the composition of that gas.
3. To determine the relative rates at which gas is released from the different coal samples.
4. To collect as much basic data as possible which, when coupled with the data from future work, will allow a more thorough understanding of the factors and conditions that affect the formation and entrapment of gas in coal.
5. To gain additional information on the geology and coal resources of the Charleston area.

TECHNIQUES AND PROCEDURES

Drilling and coring

Atec and Associates, Incorporated, of Indianapolis, Indiana, was contracted to drill one hole with a continuous core from the top of the bedrock to total depth. The core was 1.875-inches in diameter. The coal samples from seams thicker than about 2 feet were sealed into air-tight canisters as soon as possible after retrieval of the core. To minimize the time between when the coal was cored and when it was sealed into a canister, the core barrel was retrieved using a wireline. Wireline retrieval of core from a depth of 1,000 feet takes about 4 minutes as compared to conventional core drilling that requires several hours for core recovery. The other rock core was boxed at the site, was described by geologists, and was transported to the Illinois Geological Survey Annex for permanent storage. Both the core and the core description are available for inspection. Details of the drilling equipment are included in appendix B.

Measurement of concentration and composition of gas in coal samples

The total gas content of the coal is the sum of three components: "lost gas," "released gas," and "remaining gas." The amount of gas present in the coal samples is determined by measuring the amount of gas that accumulates in the canisters as a function of time (released gas). The first four or five gas measurements are used to estimate the amount of gas that was lost between the time the coal was cored and when it was sealed into the container (lost gas). The final component that must be considered is that gas which remains trapped in the micropores of the coal (remaining gas). The remaining gas is measured by crushing the coal in a sealed container and determining the amount of gas that accumulates in the container. The detailed procedures used to determine the concentration and composition of the gas are described in appendixes C, D, and E.

The procedure used for collecting coal cores and measuring their gas content is similar to the "direct method" adopted by the U.S. Bureau of

Mines (Kissell et al., 1973; McCulloch et al., 1975). The primary difference between the ISGS method and the USBM method is that our procedures allow more precise measurement of small gas volumes, and the chemical composition of the gas is monitored throughout the desorption period.

Other analyses

In addition to measuring the amount and chemical composition of the gas present in the coal, the isotopic composition of the methane and the internal surface area and porosity of the coals were measured. The procedures used for these analyses are described in appendixes F and G.

RESULTS AND DISCUSSION

Stratigraphy

Drilling began on February 26, 1979, and the hole was cemented and plugged on March 20, 1979. A general view of the drill site is shown in figure 3. The hole was projected to a depth of about 1,300 feet (395 m) to include the Seelyville Coal; however, because of caving of the hole and twisting of the drill steel, the hole had to be abandoned just below the Springfield (No. 5) Coal. Total depth of the hole was 1,121 feet (340 m). Nine coals were encountered as shown in table 2, and four of the thicker coals were collected for gas measurements.

The strata penetrated consisted primarily of shales and siltstones and occasional limestones and coals. A detailed columnar section based on a description of the core is shown in figure 4. One of the coals, the Springfield (No. 5) Coal is considered to be of minable thickness (4.4 feet).

Gas content of the coals

Five coal samples were sealed in canisters for gas measurements; one sample each from the Shelbyville (?), Danville (No. 7), and Herrin (No. 6) Coals, and two samples from the Springfield (No. 5) Coal. The No. 5 Coal was divided into two samples because the upper 1.2 feet of the seam was slightly shaly ("bone coal") and the lower 3.2 feet was normal bright banded coal.

The gas contents of the five coal samples are shown in table 3. The values for the total gas in the Shelbyville (?) and Herrin (No. 6) Coals are estimates. When the sample of Shelbyville Coal (?) was crushed, there was no increase of pressure in the jar. Therefore, it was assumed that no gas had been desorbed, and no sample was taken for chemical analysis. Later it was learned, however, that uptake of the oxygen, which was originally in the jar, by the coal can counterbalance the pressure increase caused by desorption of gas from coal (see appendix E). Without a chemical analysis, the exact amount

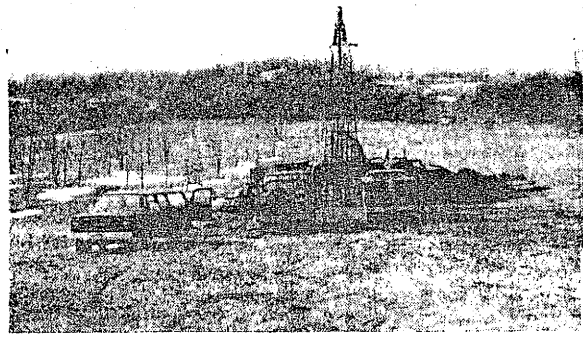


Figure 3. Drilling rig on site at the Charleston Drilling Project.

Table 2. Coals encountered in the Charleston Drilling Project

Coal	Thickness (ft)	Depth (ft)
Shelbyville (?)	1.9	504
Cohn (?)	1.0	516
Flat Creek (?)	0.8	662
Uncorrelated	1.3	700
Womac	0.55	776
Chapel (No. 8)	0.9	847
Danville (No. 7)	2.6	963
Herrin (No. 6)	2.5	1,067
Springfield (No. 5)	4.4	1,092

Note: Only those coals greater than 0.5 feet thick are listed.

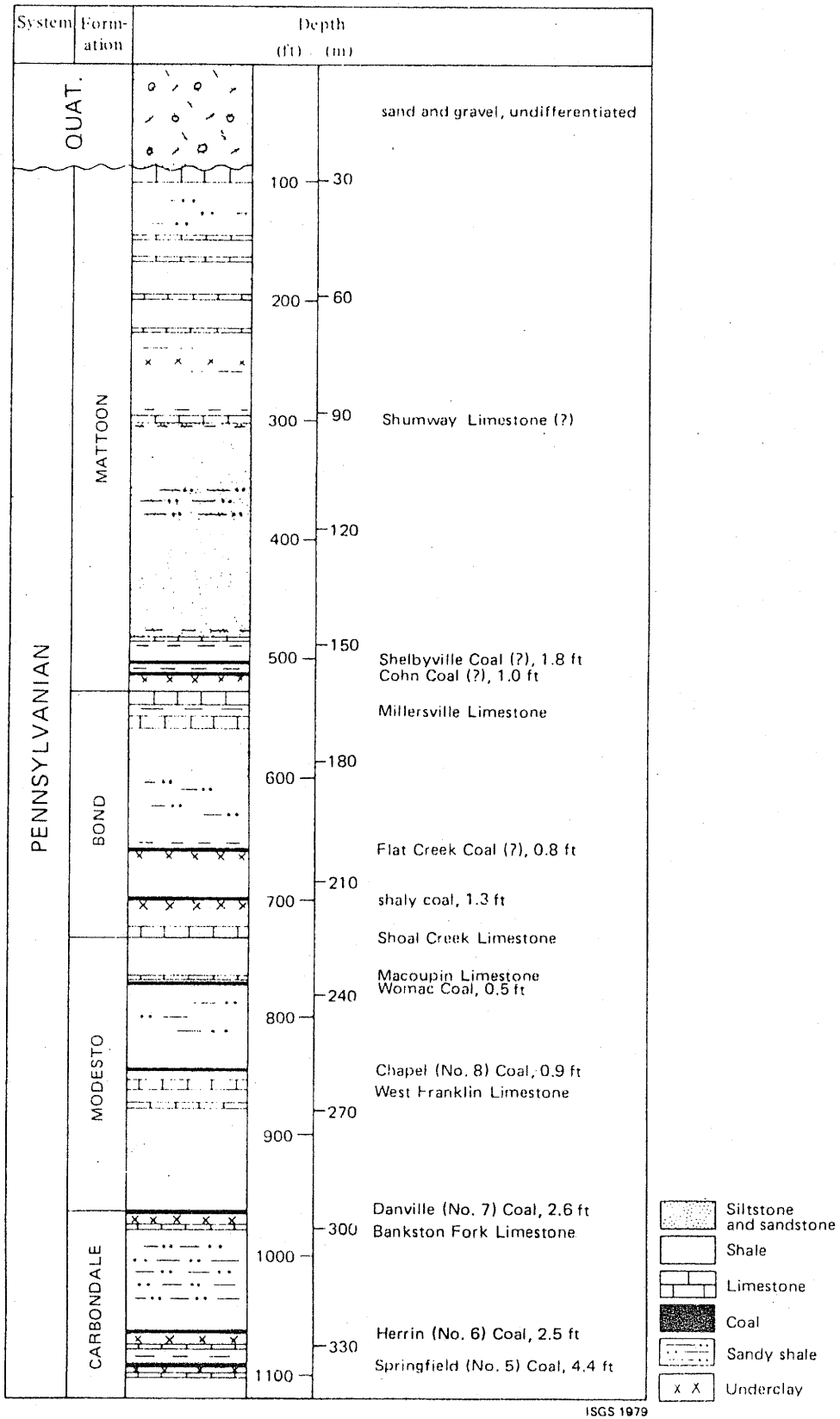
Table 3. Gas content of coals at the Charleston Drilling Project

Coal	Lost gas		Released gas		Remaining gas		Total gas	
	cm ³ /gm	ft ³ /ton	cm ³ /gm	ft ³ /ton	cm ³ /gm	ft ³ /ton	cm ³ /gm	ft ³ /ton
Shelbyville (?) ^a	.02	0.7	.12	3.8	~.1	~3	.24	8
Danville (No. 7)	.03	1.1	1.98	63.4	.70	22.5	2.71	86.7
Herrin (No. 6) ^a	.05	1.6	>.55 (.9±.1)	>17.6 (30±3)	.52	16.6	>1.1 (1.5)	>36 (48)
Springfield (No. 5)								
Upper 1.2 feet	n.d.	n.d.	.33	10.7	1.10	35.2	1.43	45.8
Lower 3.2 feet	.05	1.6	1.36	43.5	.83	26.6	2.24	71.1

Note: Volumes are at standard temperature and pressure (25°C, 1 atm).

^aSome of the values for this coal are estimates determined by the methods described in the text and in appendix E.

n.d. = none detected



ISGS 1979

CHARLESTON DRILLING PROJECT HOLE NO. 1

Figure 4. Columnar section of rocks penetrated in core drilling at Charleston.

of remaining gas cannot be determined and therefore the value for the remaining gas in the Shelbyville Coal (?) shown in table 3 is an estimate determined by the final pressure in the jar and the amount of oxygen consumption, which was estimated by comparison to other samples. Because the amount of remaining gas in this sample was very small, the error introduced by estimating the value is probably not significant.

The chemical data for the sample of Herrin (No. 6) Coal indicate that there was an undetected leak in the desorption canister and that part of the released gas was lost. Therefore, only a minimum value for the gas desorbed from this sample can be given with certainty. By monitoring the changes in chemical composition of the gas in the canister with time and comparing these data to those from other samples, the amount of gas lost through leakage can be estimated. The values for released gas given in parenthesis on table 3 are the probable values estimated by the method described in appendix G.

Compared with the gas contents of coals in some other parts of the United States, the gas contents of the Charleston coals are relatively low; however, the gas contents are similar to the values determined for coals from other parts of Illinois (table 1). Because our method of measuring the gas content of the coals differs from the "direct method" of the U.S. Bureau of Mines (McCulloch et al., 1975) and because all previously reported gas content measurements for Illinois coals are based on the Bureau of Mines method, a comparison of our results with the results obtained by the direct method is shown in table 4. The results from the two methods are similar; however, it is believed that the techniques used in this study are more precise than the USBM method, particularly for coals having low gas contents.

Table 4. Gas contents of Charleston coals as determined by the U.S. Bureau of Mines method and by the Illinois State Geological Survey method

Coal	Direct method		ISGS method	
	cm ³ /gm	ft ³ /ton	cm ³ /gm	ft ³ /ton
Shelbyville (?)	~ 0.4	~ 1.2	~ .24	~ 8
Danville (No. 7)	3.3	106	2.7	86.7
Herrin (No. 6)	.85	27.1	~ 1.4	~ 47
Springfield (No. 5)				
Upper 1.2 feet	.49	15.6	1.4	45.8
Lower 3.2 feet	2.2	69.7	2.2	71.1

Rate of gas release from the coals

Although the amount of gas present is an important factor in evaluating the production capabilities of a particular coal seam, the ease with which the gas is released from the coal must also be considered. To facilitate determination of gas release rates, the desorption of gas from the canned coal samples was monitored for several months. To a first approximation, the rate of gas release may be measured independently of total gas content by monitoring the fraction of total gas released as a function of time. By computer curve fitting, it was found that the data for the first 10 days of the desorption tests could be closely approximated by an equation of the form

$$F = \frac{A_t}{A_\infty} = \alpha t^b \quad (1)$$

where F is the fraction of total gas released at time t , A_t is the amount of gas released at time t , A_∞ is the total gas content of the coal, and α and b are constants. Values of α , b , A_∞ , and the correlation coefficients that were determined are given in table 5.

The correlation coefficient is an estimate of the "goodness of fit." A correlation coefficient of 1.0000 would indicate that all data points fell exactly on the line. The fit of the data to these curves is surprisingly good.

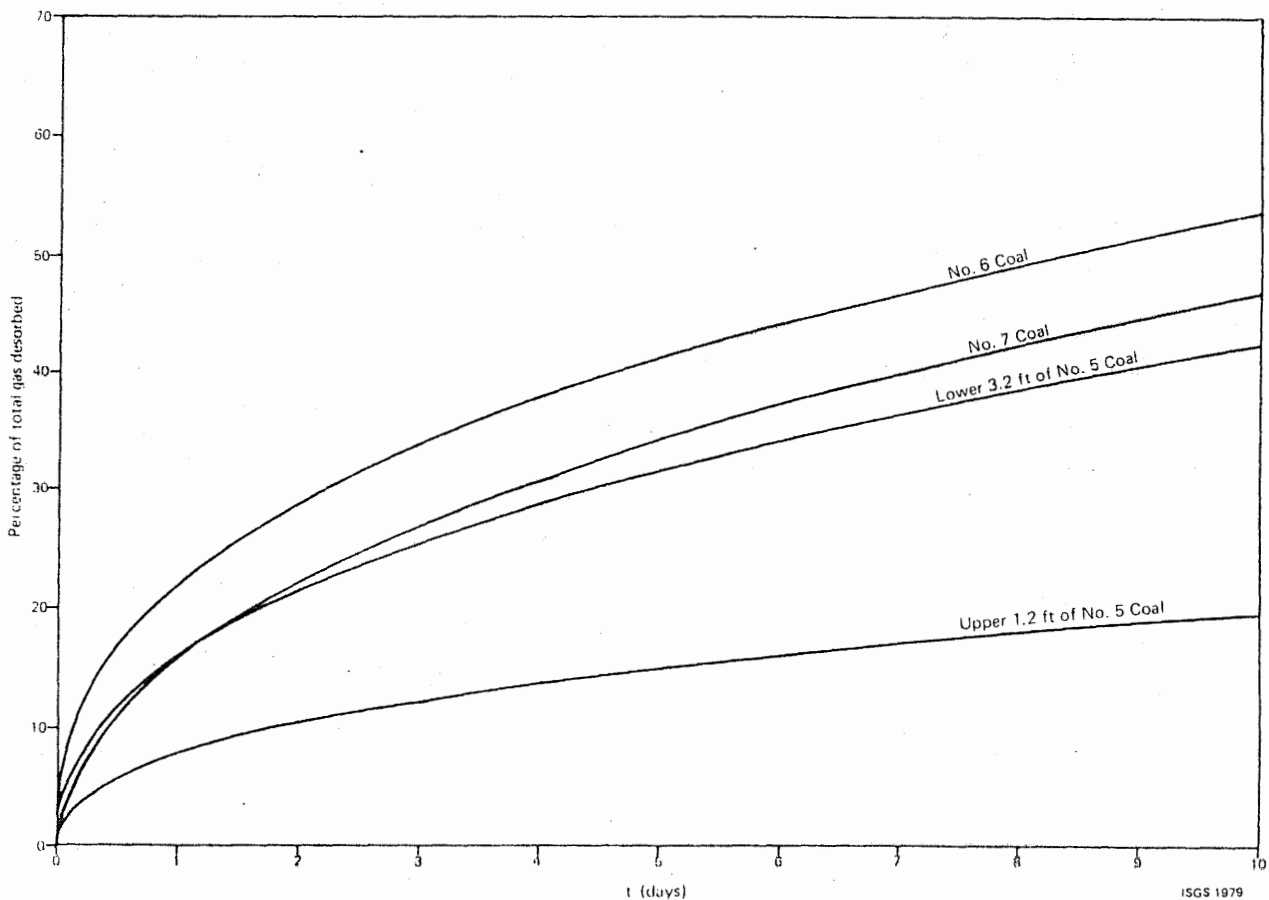


Figure 5. Percentage of total gas released as a function of time for the coal samples studied.

Table 5. Coefficients of the equation $F = at^b$ which describe the desorption rates of the coal samples

Coal	Constants			Correlation coefficient	$I = aA_{\infty}b$
	A_{∞} (cm ³ /gm)	a	b		
Danville (No. 7)	2.7	.160	.469	.9983	.202
Herrin (No. 6)	1.4	.220	.387	.9977	.119
Springfield (No. 5)					
Upper 1.2 feet	1.4	.0073	.406	.9979	.044
Lower 3.2 feet	2.2	.158	.430	.9988	.149

Using the equations determined for the different coals, the percentage of total gas released (% = 100 F) is graphed on figure 5 for each coal. The figure shows that the No. 6 Coal releases its gas most rapidly, followed by the No. 7 Coal, and the lower 3.2 feet of the No. 5 Coal. The upper 1.2 feet of the No. 5 Coal (bone coal) released its gas at a much slower rate than the others.

The effects of gas release rate and gas content can be combined by rearranging equation (1) to give

$$A_t = aA_{\infty}t^b. \quad (2)$$

The gas release curves determined for the different coals are shown on figure 6. The significance of the difference in release rate can be observed by noting that although the No. 6 Coal contained approximately the same amount of gas as the upper 1.2 feet of the No. 5 Coal, after 10 days of desorption the No. 6 Coal had released nearly three times as much gas as the upper 1.2 feet of the No. 5 Coal.

Differentiation of equation (2) gives

$$\frac{dA_t}{dt} = abA_{\infty}t^{b-1}. \quad (3)$$

Using this equation, it may be possible to define an index number "I" for comparing the gas productivity of different coal samples, where $I = a \cdot b \cdot A_{\infty}$. Values of I for the coals tested are also given in table 5.

The usefulness of this index factor may be observed by noting that the I value for the No. 7 Coal is about 1.7 times that of the No. 6 Coal, and after 10 days, the No. 7 Coal had released 1.7 times as much gas as the No. 6 Coal. Similar relationships exist for the other coal samples. The I value therefore provides an indication of the gas productivity of the different coal samples and accounts for both the total gas content of the coal and the release rate.

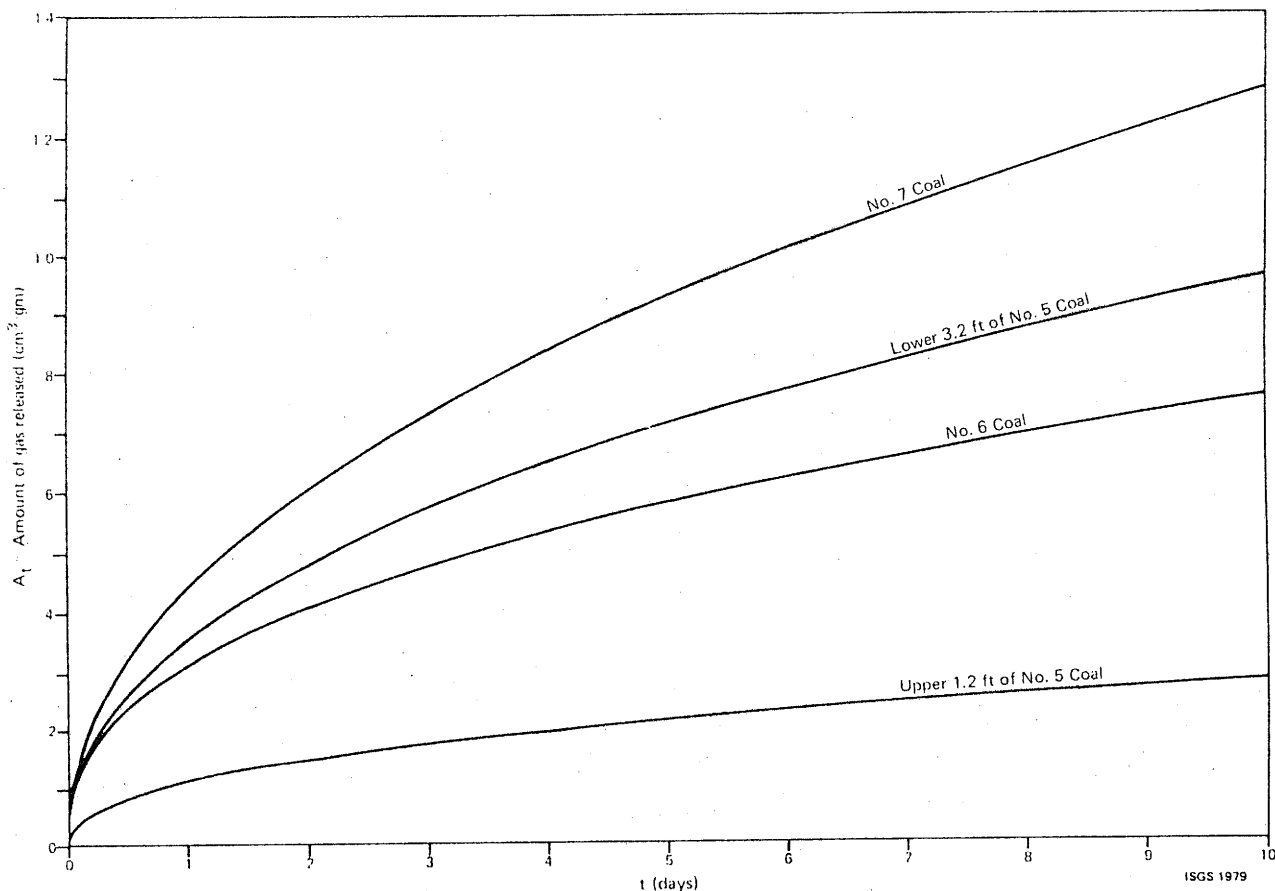


Figure 6. Amount of gas released as a function of time.

It should be emphasized that the data presented here pertain only to the particular core samples desorbed in the laboratory under controlled conditions. It is not known how, or if, this information would relate to the production capabilities of a well that was completed in these coals or to other samples of the same coal. Such information could only be obtained by additional testing and direct comparison of laboratory data to field production data.

Internal surface area and porosity data

Coal is a rock consisting largely of decomposed organic matter. Unlike most rock core, a coal core has a large internal surface area because it contains millions of very small open pores within its structure (Thomas and Damberger, 1976). Most of the gas trapped within the coal adheres to the surfaces of the pores, and an estimation of the total internal surface area is useful for determining the potential for gas adsorption by the coal. The internal surface area (ISA) data for the five coal core samples investigated in this study and the total porosity data for three of the five coal core samples are given in table 6. The method of determination is described in appendix G.

Internal surface area measurements using nitrogen as the adsorbate at -196°C and carbon dioxide at -77°C are important in determining the nature of the porosity present in coal. Published studies have shown that much of the internal surface area in coals is associated with ultra-micropores having diameters less than 5 \AA (Thomas and Damberger, 1976). Carbon dioxide at -77°C is able to penetrate pores having diameters less than about 5 \AA whereas N_2 at

-196°C is unable to do so. Thus, the CO₂/N₂ internal surface area ratio provides a measure of the degree of ultra-microporosity present in the coal sample; the higher the CO₂/N₂ ISA ratio, the greater the degree of microporosity. The degree of microporosity is also indicative of the difficulty involved in the migration of sorbed gases and vapors from within a coal particle to the external surface of the coal particle (i.e., the diffusion permeability). If all factors, such as particle size of the coal, concentration of sorbed gases and vapors, and fractures present in the coal particles, are equal, then the higher the degree of microporosity present, the slower the migration rate will be.

Table 6 shows that a significant fraction of the pores in the coal samples are micropores less than 4 Å to 5 Å in diameter or are pores having micropore entrances. In agreement with the desorption data, the CO₂/N₂ ISA ratios predict that of the four coal samples that contained significant amounts of gas the No. 6 Coal should have the greatest release rate. The CO₂/N₂ ISA ratios also suggest that the No. 7 Coal, the upper 1.2 feet of the No. 5 Coal, and the lower 3.2 feet of the No. 5 Coal should have very similar gas release rates; however, figure 5 shows that in actuality there were large differences in the gas release rates of these coals.

The lack of correlation between the gas release data and the ratios of ISA and CO₂/N₂ ISA is interpreted as indicating that coal permeability by itself is not the major factor controlling the rate at which gas is released from coals. The presence and abundance of microfractures, for example, may be the predominant factor controlling gas release rates. For that reason, the gas release rates observed for bulk samples may be more useful for predicting the gas productivity of a coal seam than are porosity and permeability data.

Table 6 also shows the total porosity of several of the coals. The total porosity correlates very closely with the ISA (CO₂). The data indicate that the No. 6 Coal has the highest ISA (CO₂) and highest total porosity and, therefore, the greatest "capacity" for gas adsorption; the No. 7 Coal and the upper 1.2 feet

Table 6. Internal surface area and porosity data

Sample	N ₂ ISA (m ² /g)	CO ₂ ISA (m ² /g)	CO ₂ /N ₂ ISA ratio	Total porosity (%)	Total porosity (cc/g)
Shelbyville	32.9	140.5	4.3	---	---
Danville (No. 7)	16.4	168.4	10.3	8.1	0.065
Herrin (No. 6)	41.5	192.2	4.6	11.6	0.087
Springfield (No. 5)					
Upper 1.2 feet	15.5	169.6	10.9	---	---
Lower 3.2 feet	15.9	158.3	9.9	7.3	0.060

of the No. 5 Coal have very similar capacities which are greater than that of the lower 3.2 feet of the No. 5 Coal. This is not in agreement with measured gas contents of these coals and indicates that gas "capacity" and gas content are not directly correlative.

Chemical composition of the gases

The chemical compositions of the gases collected from the coal cores are summarized in table 7. These values were obtained by summing the amounts of each chemical component present in all gas samples taken from a single coal core. The methods used to carry out these calculations are described in appendix D. Pentane (C_5H_{12}) was also detected but was present only at the parts per million level and is therefore not shown in table 7.

The gases are characterized by relatively high nitrogen values and high ethane (C_2H_6), propane (C_3H_8), and butane (C_4H_{10}) values when compared with the compositions of coals from the eastern United States or with gases produced from abandoned coal mines in Illinois. The gases from the Charleston coals are more similar in composition to gases associated with petroleum deposits in Illinois.

Due to the nature of the method of determining the composition of the gas (appendix D), the value that is most subject to error is the percentage of nitrogen. This value is dependent on the amount of nitrogen originally in the canister, which is calculated by using the density of the coal. Density measurements are made on relatively small splits of the samples and may therefore not be equal to the bulk density of the whole sample. If the value for the density were too low, the percentage of nitrogen shown in table 5 would be too high, and vice versa. This would not affect the relative proportions of the other components, however.

There are distinct changes in the composition of the gas as it desorbs from the coal. The first gas released is generally enriched in nitrogen and methane and is depleted in carbon dioxide and heavier hydrocarbons relative to gas released later or to "remaining gas." This phenomenon is in agreement with predictions based on differences in mass, size, and adsorptivity of the different molecules. There are also significant differences between the compositions of the gases from some of the coals. The compositions of the gases from the No. 5 and No. 6 Coals are similar to each other but differ significantly from the composition of the gas from the No. 7 Coal. For example, the ratio of methane to ethane for the No. 5 and No. 6 Coals is about 9, whereas the ratio for the No. 7 Coal is about 24. There are also distinct differences in the proportions of the different isomers of butane and pentane present. The gases from the No. 5 and No. 6 Coals have approximately equal proportions of iso-butane and normal-butane whereas the gas from the No. 7 Coal has approximately ten times as much iso-butane as normal-butane. The No. 5 and No. 6 Coals have about three times as much iso-pentane as normal-pentane whereas the No. 7 Coal contained only iso-pentane. These differences imply that there are differences in the origins and/or histories of the gases in the different coals. The nature and implications of the differences between the gases in the different coals are still under study and will be discussed in a future publication.

Table 7. Chemical composition of gases desorbed from the Charleston coals

Coal		CO ₂ (%)	N ₂ (%)	CH ₄ (%)	C ₂ H ₆ (%)	C ₃ H ₈ (%)	C ₄ H ₁₀ (%)	BTU gross
Shelbyville (?)	Released gas	17	25	54	3	1	--	~930
	Trapped gas				NO DATA			
	TOTAL GAS	INSUFFICIENT DATA						
Danville (No. 7)	Released gas	1.9	15.1	80.2	2.2	0.5	0.1	867
	Trapped gas	3.1	13.9	73.5	6.6	2.5	0.4	940
	TOTAL GAS	2.2	14.8	78.5	3.3	1.0	0.2	886
Herrin (No. 6) ^a	Released gas	< 3.7 (2.7±.1)	> 0 (25±4)	< 88.9 (66±3)	< 4.6 (3.4±.2)	< 2.4 (1.8±.1)	< .4 (.3±.1)	< 1061 (785±35)
	Trapped gas	5.5	16.6	48.8	15.9	11.1	2.1	1440
	TOTAL GAS	< 4.5 (3.7±.1)	> 7.7 (22±3)	< 70.4 (60±2)	< 9.8 (7.8±.4)	< 6.4 (5.0±.2)	< 1.2 (1.0±.1)	< 1240 (1010±40)
Springfield (No. 5)	Released gas	6.1	35.7	53.9	2.6	1.3	.4	640
	Trapped gas	3.2	15.3	66.3	8.9	5.4	.9	1001
	Upper 1.2 feet	TOTAL GAS	3.9	20.0	63.4	7.4	4.5	.8
Springfield (No. 5)	Released gas	1.4	21.1	70.4	4.5	2.2	.4	862
	Trapped gas	2.5	16.2	63.2	10.7	6.1	1.3	1032
	Lower 3.2 feet	TOTAL GAS	1.8	19.3	67.8	6.8	3.6	.7

^aSome of the values for this coal are estimates determined by the methods described in the text and in appendix E.

Carbon isotopic composition of methane

The information obtained by monitoring the desorption of gas from core samples makes it possible to determine the gas content of coals at the drill site. To extrapolate this information to untested areas, it is necessary to determine the geological factors and conditions that control gas formation, migration, and accumulation.

Although the chemical composition of natural gas can provide some information about its origin and history, the chemical composition of a gas can change as the gas migrates through rocks (Coleman et al., 1977; Coleman and Meents, 1978). A more definitive technique for studying the origin and history of natural gas is isotopic analysis of the methane. The ratio of the carbon-13 isotope to the carbon-12 isotope in methane is a function of the mode and conditions of formation of the gas and is relatively unaffected by migration. The C^{13}/C^{12} ratio can therefore be used to "fingerprint" gases of different origins (Fuex, 1977; Stahl, 1977).

The isotopic compositions, expressed as δC^{13} values (see appendix E), of several samples from the No. 5, No. 6, and No. 7 Coals were determined and are summarized in Table 8. As with the chemical composition, the isotopic composition of the gas changes with time. The change in the isotopic composition, however, is much less than the change in the chemical composition. The isotopic compositions of these gases are somewhat different than the isotopic compositions of gases from coals in other areas. Stahl (1977) has found that there is a correlation between the isotopic composition of methane and the nature and rank (of thermal maturity) of the source material. Stahl's data indicate that methane formed from sapropelic material (which is frequently attributed to the formation of petroleum), and having a degree of thermal maturity similar to that of coals in the Charleston area, would be expected to have a δC^{13} value in the range of -40 to -55‰. Humic source material such as is predominant in Illinois coals would be expected to produce methane having a δC^{13} value in the range of -25 to -40‰.

Table 8. Carbon-isotopic composition of methane from gas samples (The range shown for the released gas is the change in isotopic composition from the first sample collected to the last sample.)

Coal	Type gas	Number of samples analyzed	$\delta C^{13} CH_4$ (‰)	
Danville (No. 7)	released	9	-62.9 to -61.4	
	remaining	1	-59.8	
Herrin (No. 6)	released	4	-57.4 to -55.1	
	remaining	1	-52.1	
Springfield (No. 5)	Upper 1.2 feet	released	-57.1 to 56.5	
		remaining	-55.4	
	Lower 3.2 feet	released	7	-57.3 to -55.6
		remaining	1	-54.5

Although the amount of data available is too limited to draw definite conclusions about the origin of the gas found in the coals of the Charleston area, the possibility must be considered that this gas was formed in the overlying and/or underlying shales and has migrated into the coals. If this is true, the nature of the other rocks present would merit consideration in looking for areas likely to have significant gas accumulations.

As was true for the chemical compositions of the gases, there are distinct differences in the isotopic composition of the methane from the different coals. The gases from the No. 5 and No. 6 Coals are isotopically similar, but distinctly different than the gas from the No. 7 Coal; this suggests again that there are differences in the origins and/or histories of these gases. The isotopic data will be discussed in greater detail in a future publication.

CONCLUSIONS

1. A continuous core of the rock strata drilled to a total depth of 1,121 feet penetrated nine coals that were greater than 0.5 feet thick. One of these, the Springfield (No. 5) Coal is considered to be of minable thickness (4.4 feet).
2. The gas content of four coals was measured and found to range from approximately 8 ft³/ton to more than 86 ft³/ton. These values are within the range of gas contents of other Illinois coals as determined by previous studies. The gas contents of these coals are relatively low when compared with some other coals in the United States, which are characterized by high gas emissions during mining and/or by gas production from boreholes.
3. Significant differences in the rates at which gas is released from the coals were observed; the Herrin (No. 6) Coal releases its gas most readily. An "index of gas productivity" is proposed that may allow easy comparison of different coal samples.
4. Comparison of internal surface area and porosity data to desorption data indicates that porosity and permeability type data do not accurately predict the gas contents or the gas release rates.
5. The gases from the coals that were studied are characterized by a relatively high nitrogen content and high ethane, propane, and butane contents when compared with gases from coals in other areas. The heating value of the gases ranges from about 850 to 1,000 BTU per standard cubic foot of gas.
6. The chemical and isotopic compositions of the gases are somewhat different than those of gases from coals in other areas, but similar to gases related to petroleum deposits in Illinois. The possibility must be considered that these gases formed elsewhere and migrated into the coals.
7. The chemical and isotopic composition of the gas from the No. 7 Coal is distinctly different from that of the gas from the No. 6 and No. 5 Coals; this suggests that the origin and/or histories of these gases is different.

APPENDIXES

Appendix A. Selected list of references to gas in coal

- Cervik, J., 1969, Behavior of coal-gas reservoirs: U.S. Bureau of Mines Technical Progress Report 10, 10 p.
- Deul, M., 1975, Natural gas from coalbeds: Presented at Forum on Natural Gas Potential of Unexploited Sources, Natural Resources Council, Washington, DC, January 15, 1975. (Chapter in Natural Gas from Unconventional Geologic Sources, 1976, p. 193-205.)
- Deul, M., and A. G. Kim, 1975, Coalbeds: a source of natural gas: Oil and Gas Journal, v. 73, no. 24, p. 47-49.
- Hadden, J. D., and J. Cervik, 1969, Gas migration characteristics of coalbeds: U.S. Bureau of Mines Technical Progress Report 12, 10 p.
- Kim, A. G., 1973, The composition of coalbed gas: U.S. Bureau of Mines Report of Investigations 7762, 9 p.
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- Kim, A. G., 1977, Estimating methane content of bituminous coalbeds from adsorption data: U.S. Bureau of Mines Report of Investigations 8245, 22 p.
- Kissell, F. N., 1972, The methane migration and storage characteristics of the Pittsburgh, Pocohontas No. 3, and Oklahoma Hartshorne coalbeds: U.S. Bureau of Mines Report of Investigations 7667, 22 p.
- Kissell, F. N., and J. C. Edwards, 1975, Two-phase flow in coalbeds: U.S. Bureau of Mines Report of Investigations 8066, 16 p.
- Perkins, J. H., and J. Cervik, 1969, Sorption investigations of methane on coal: U.S. Bureau of Mines Technical Progress Report 14, 6 p.
- Popp, J. T., and C. M. McCulloch, 1976, Geological factors affecting methane in the Beckley Coalbed: U.S. Bureau of Mines Report of Investigations 8137, 35 p.
- Price, H. S., R. G. McCulloch, J. E. Edwards, and F. N. Kissell, 1973, A computer model study of methane migration in coalbeds: Presented at Canadian Institute of Mining Annual Western Meeting, Saskatoon, Sask., October, 1972, Canadian Mining and Metallurgical Bulletin, September, 1973, p. 103-112.
- Selden, R. F., 1934, The occurrence of gases in coal: U.S. Bureau of Mines Report of Investigations 3233, 64 p.
- Thimons, E. D., and F. N. Kissell, 1973, Diffusion of methane through coal: Fuel, v. 52, p. 274-280.

Appendix B. Drilling equipment

- | | |
|----------------------------------|---|
| 1. Make and model of drill rig | Mobil drill, B-61
(truck mounted) |
| 2. Drill rig drilling capability | Approximately 2,000 ft,
NX wireline |
| 3. Drilling fluid | Fresh water |
| 4. Size of work crew | 3 |
| 5. Core bit size | NX series O.D.—2.98 in.
I.D.—1.875 in. |
| 6. Core barrel type and length | Wireline retrievable, 16 ft. |
| 7. Casing | HQ series O.D.—3.5 in.
I.D.—3.0625 in. |
| 8. Drill/Steel | NQ series O.D.—2.75 in.
—2.375 in. |
| 9. General information | Work schedule included one shift working approximately dawn to dusk (10 to 12 hrs per day); drill tools remained in the hole at night. Casing was set with drilling mud behind it, but no mud was used during drilling. |

Appendix C. Collection and desorption of coals

Coal cores were sealed into air-tight, 2.8 liter capacity, aluminum canisters (fig. A) as quickly as possible after being removed from the drilling core barrel, allowing only time for thickness measurements and a quick core description. The lids of the canisters are fitted with rubber septa, and pressures were measured by piercing the septa with a hypodermic needle attached to a pressure gauge. The release of gas from the coal causes the pressure in the canister to gradually increase. The gas that accumulates in the canister is referred to as "released gas." This gas is bled off at timed intervals, and the volume released is measured. Each time the gas is bled off, a sample is collected for chemical analysis by simultaneously plunging a double-ended hypodermic needle into the canister and into an evacuated 26 cm³ sample bottle. If there is a positive pressure in the canister after sampling, additional gas is bled off into another bottle (the size of which depends on the amount of gas present) and is collected by water displacement (see fig. B). The amount of gas in this bottle is measured by determining the weight of the water displaced. Other factors, such as barometric pressure, canister pressure, and temperature, are measured each time samples are taken and recorded. The amount of coal present is determined by weighing the canisters before and after they are loaded.

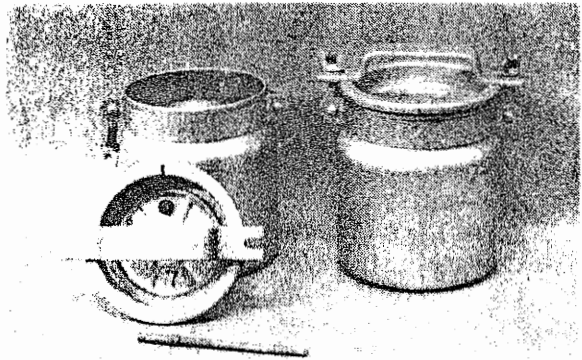


Figure A. Aluminum canisters used for desorption of coal samples.

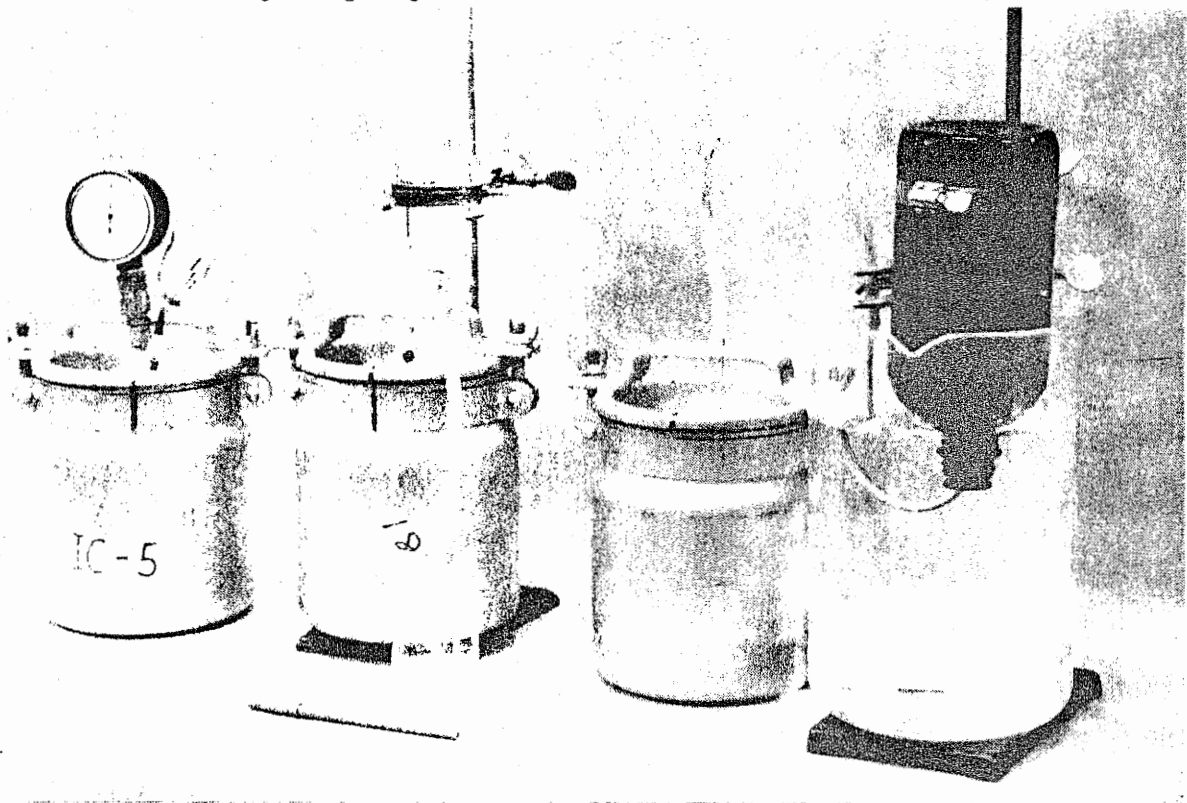


Figure B. Monitoring the pressure and taking gas samples. The size of sample bottle used is varied with the amount of gas present.

The coal continues to desorb gas until much of the gas trapped in the coal has been released. This release may take several weeks or several months. When the rate of gas release becomes negligible, the coal is quickly removed from the canister, a portion for petrographic and chemical analysis is removed with a dry saw, and the coal is weighed and sealed into a ceramic ball jar for crushing. The ball jar and the grinding media used are shown in figure C. After tumbling the jar on a roller mill for several hours, the pressure is measured through a rubber septum in the lid of the ball jar, and the gas is sampled and measured as previously described. The gas released by crushing the coal is referred to as "remaining gas". The jar is then opened, and the coal is inspected to determine if crushing is complete. If there are any uncrushed portions, they are weighed and that weight is subtracted from the total weight of coal in the jar to determine the amount of coal that was crushed. If the proportion of grinding media to coal and the tumbling time are chosen properly, the coal will be completely ground to a fine powder. Pyrite and other mineral matter may survive the crushing.

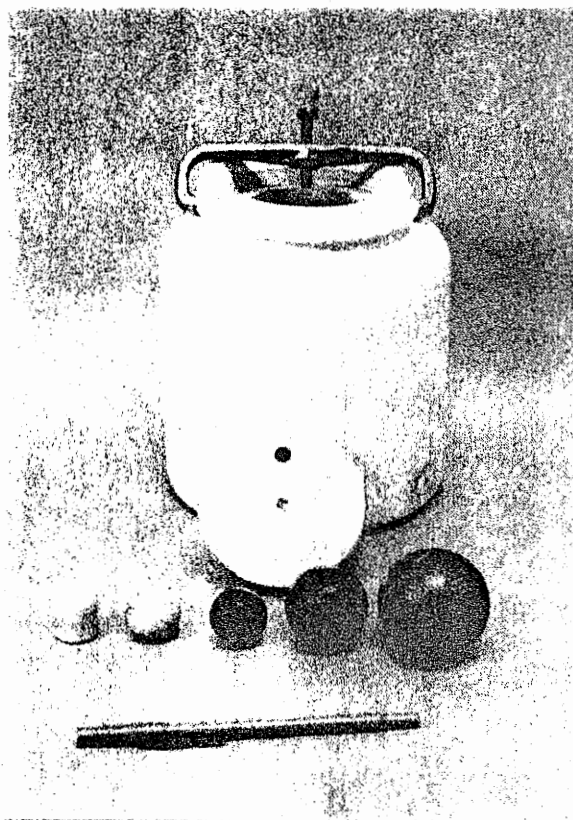


Figure C. Ceramic ball jar used for crushing coal samples. The ball jar is fitted with a rubber lined aluminum lid containing a septum for measuring pressures and taking gas samples. Ceramic and iron grinding media of different sizes and shapes are used to promote thorough crushing.

Appendix D. Method of gas analysis

Gases desorbed from the sealed cores were analyzed to determine their chemical compositions. The chemical composition of the gas must be known to accurately determine the volume of gas released (discussed in the next section), to evaluate the heating value of the gas, and to compare the gas to that from other sources. Gas samples were collected for chemical analysis each time a gas volume determination was made. All analyses were on sample splits that had been collected in evacuated 26 cm³ bottles because the composition of those splits collected by water displacement may have been affected by equilibration with the water.

Chemical analyses of the gases were performed on a Perkin Elmer Sigma 1 gas chromatographic system. A CTR column was temperature programmed to separate CO₂, O₂, N₂, and the C₁ to C₅ alkanes by using the hot-wire detector. Also, a Chromosorb 102 column was run isothermally connected to the flame ionization detector for detection of the hydrocarbons that were below the detection limits of the hotwire detector. Gas concentrations are reported as percentage of volume. During analysis, oxygen and argon are not separated, therefore values reported for oxygen are actually oxygen plus argon.

Appendix E. Determination of gas volumes

Because the coal samples do not completely fill the desorption canisters, there is a significant amount of air in the canister when it is sealed. To accurately correct for temperature and pressure variations and to determine the chemical composition of the gas being emitted by the coal, the amount of air initially in the canister must be precisely known. The volume of the empty canister can be easily measured, but the volume of the coal must be calculated using the density of the coal. The density is measured by water displacement using a technique similar to the ASTM method for determining the density of coke. The headspace in the canister equals then the volume of the empty canister minus the volume of the coal.

Although the actual volume of the headspace for any particular sample is constant, the amount of gas present in that space is a function of temperature and pressure. Therefore, the volume of gas in the canister when corrected to standard temperature and pressure (25°C and 1 atmosphere) is not a constant. The temperature and pressure correction can be very significant. For example, if a canister with a headspace of 1,500 cm³ were sealed at a temperature of 0°C and then taken to a laboratory where the temperature was 27°C, there would be an increase in pressure in the canister caused by expansion of the gas. If the gas were then bled off until the canister was again at atmospheric pressure, the amount of gas removed would be approximately 145 cm³, even if there were no gas desorbed from the coal. The amount of gas desorbed from the coal is therefore the total amount of gas released corrected for the temperature effect. A similar effect can be caused by variations in the atmospheric pressure because pressure gauge readings are always relative to atmospheric pressure. Therefore the atmospheric pressure was recorded each time a sample was taken. All pressure gauges used were calibrated against a mercury manometer.

Another phenomenon that can cause erroneous results is the effect of oxidation of the coal. Because the air originally in the canister is approximately 21 percent oxygen (actually oxygen plus argon), a significant amount of oxidation can occur; it is probably the result of reaction of oxygen with pyrite and other inorganic constituents in the coal. In the hypothetical situation outlined above, the volume of air originally present in the canister when corrected to standard temperature and pressure (STP) equals 1,633 cm³. If all of the oxygen present were to react with the coal, there would be a volume decrease of approximately 340 cm³. Therefore, more than 340 cm³ of gas would have to be released from the coal before the canister would show a positive pressure. For that reason, a close monitoring of the chemical composition of the gas in the canister is necessary.

The sampling time, the volumes of the sample removed and the head space in the canister, and the chemical composition of the sample are entered into a computer program, in order to calculate the amount and composition of the released gas. An example of the input data is shown in table A. This information can be used to monitor the volume of each component released from the coal. The volume of any component that has been produced at any given time equals the volume that has been removed in the samples taken plus the volume left in the canister. The computer printout shown in table B lists the cumulative volumes of each component released from the coal as a function of time. Table B shows that the oxygen is being consumed with time; this provides evidence for the oxidation reaction previously discussed.

INPUT DATA

G.C. ANALYSIS

SAMPLE NO.	TIME (MIN)	VOLUME SAMPLE (CC)	VOLUME CAN (CC)	XC02	XC02	XC02	XC01	XC02	XC03	XC04
20-00	13.	0.0	1352.	.03	21.08	78.04	0.00	0.00	0.00	0.00
20-01	28.	53.8	1352.	.19	20.45	77.41	1.05	.07	.02	0.00
20-03	43.	26.0	1344.	.19	20.07	76.80	2.79	.11	.03	0.00
20-04	58.	20.8	1352.	.21	19.62	76.03	3.94	.15	.04	0.00
20-05	137.	20.8	1355.	.29	18.47	73.47	7.20	.30	.25	.02
20-06	1082.	482.2	1290.	.34	11.91	64.20	21.88	1.04	.48	.08
20-07	2507.	231.5	1290.	.39	7.44	58.71	30.76	1.68	.85	.15
20-08	3997.	119.5	1290.	.49	5.11	55.71	35.58	2.00	.91	.17
20-09	5442.	67.5	1294.	.56	3.00	53.78	38.50	2.22	1.11	.20
20-10	6897.	58.2	1308.	.65	2.01	51.94	41.16	2.31	1.10	.20
20-11	9767.	180.6	1275.	.74	1.69	49.11	44.36	2.62	1.20	.24
20-12	11177.	77.4	1285.	.84	1.55	48.31	44.79	2.86	1.39	.16
20-13	12892.	69.5	1284.	.93	1.40	46.60	46.18	3.05	1.57	.22
20-14	15677.	115.1	1285.	1.04	1.33	44.72	48.12	2.95	1.57	.24
20-15	19767.	77.0	1279.	1.29	1.04	43.26	48.93	2.99	1.62	.24
20-16	22712.	58.5	1274.	1.14	1.57	42.21	50.09	3.24	1.67	.24
20-17	25647.	73.0	1275.	1.19	1.55	41.10	50.75	3.34	1.78	.25
20-18	30112.	56.6	1271.	1.19	1.56	40.36	51.66	3.33	1.60	.25
20-19	32867.	78.7	1275.	1.37	1.79	39.10	52.33	3.42	1.67	.28
20-20	40097.	83.6	1264.	1.37	1.42	37.42	54.45	3.47	1.53	.30
20-21	42857.	62.7	1269.	1.30	1.41	36.71	55.31	3.39	1.57	.27
20-22	45767.	25.2	1273.	1.26	1.84	36.91	54.74	3.41	1.53	.27
20-23	52977.	25.0	1295.	1.24	1.55	35.50	56.51	3.49	1.59	.28
20-24	55852.	51.3	1284.	1.40	1.99	35.09	55.51	3.77	1.91	.29
20-25	66347.	81.1	1269.	1.32	1.89	34.58	56.22	3.72	1.92	.30
20-26	68822.	25.3	1282.	1.35	1.64	33.82	57.09	3.73	2.01	.32
20-27	74672.	57.1	1260.	1.19	.80	31.35	60.25	3.74	2.35	.28
20-28	80312.	50.9	1273.	1.21	1.02	31.43	59.92	3.80	2.30	.29
20-29	86142.	50.7	1273.	1.21	.62	30.34	61.31	3.86	2.11	.29
20-30	116297.	88.7	1270.	1.16	.74	29.26	62.70	4.00	1.77	.31
20-31	150857.	141.2	1281.	1.24	.63	27.46	64.10	4.21	1.94	.37
20-32	160922.	72.4	1268.	1.39	.84	27.30	63.54	4.38	2.12	.38

Table A. Example of data used for calculation of amount and composition of released gas.

GAS PRODUCTION DATA

CUMULATIVE GAS PRODUCTION DATA

SAMPLE NO.	TIME (DAYS)	SQRT TIME (MIN)	CO ₂ (CC)	O ₂ (CC)	N ₂ (CC)	CO (CC)	CO ₂ (CC)	CO ₃ (CC)	CO ₄ (CC)	TOTAL (CC)
20-00	.009	3.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20-01	.019	5.29	2.3	-0.3	32.5	20.0	1.0	.3	0.0	62.0
20-03	.030	6.56	2.3	-9.7	30.5	39.2	1.5	.4	0.0	82.0
20-04	.040	7.62	2.0	-9.0	54.0	50.1	2.1	.6	0.0	116.0
20-05	.095	11.70	3.0	-19.0	41.4	102.3	4.3	3.5	.3	156.0
20-06	.151	32.09	5.9	-57.5	106.0	393.0	19.6	0.6	1.4	617.3
20-07	1.741	50.07	7.5	-90.7	249.1	570.2	31.0	15.3	2.7	883.7
20-08	2.770	63.22	9.3	-122.6	277.0	682.9	37.5	17.2	3.1	1027.0
20-09	3.779	73.77	10.6	-139.5	290.4	748.0	41.9	20.6	3.7	1115.2
20-10	4.790	83.05	12.3	-150.4	304.1	812.1	44.8	21.2	3.8	1198.3
20-11	6.783	98.63	14.5	-160.0	339.6	919.5	52.7	24.3	4.7	1355.3
20-12	7.762	105.72	16.5	-160.4	370.0	963.2	58.2	27.9	3.8	1440.3
20-13	8.953	113.54	18.3	-161.4	381.3	1013.0	62.8	31.3	4.7	1512.3
20-14	10.687	125.21	21.0	-160.7	409.3	1094.4	64.9	33.2	5.3	1628.0
20-15	13.741	140.67	25.1	-155.0	421.3	1139.5	67.0	35.0	5.4	1693.0
20-16	15.772	150.71	23.8	-150.3	430.3	1181.0	72.5	36.5	5.6	1749.7
20-17	17.610	160.15	25.3	-154.9	440.0	1226.3	76.2	39.2	5.9	1818.9
20-18	20.911	173.53	25.9	-153.9	450.7	1266.1	77.9	37.8	0.0	1872.3
20-19	22.824	181.29	29.3	-149.5	475.0	1317.9	81.8	40.0	0.0	1950.7
20-20	27.045	200.24	30.3	-153.2	480.7	1384.4	85.0	39.4	0.0	2021.0
20-21	29.762	207.02	30.3	-152.4	496.0	1432.8	86.3	40.9	0.9	2093.0
20-22	31.783	213.93	30.2	-146.4	509.9	1441.5	87.5	40.9	7.0	2117.0
20-23	36.790	230.17	30.5	-149.3	500.9	1488.3	90.2	42.4	7.2	2167.5
20-24	38.780	230.33	33.2	-142.0	517.7	1500.3	95.4	47.3	7.5	2201.3
20-25	46.074	257.58	33.0	-142.9	534.0	1546.6	97.2	48.7	7.8	2267.3
20-26	47.793	262.34	33.9	-145.4	537.3	1579.5	98.7	50.6	8.2	2306.3
20-27	51.050	273.26	32.3	-153.0	510.5	1644.8	100.4	55.9	7.8	2359.8
20-28	55.772	283.39	33.3	-152.5	537.0	1675.3	103.4	56.0	0.1	2414.4
20-29	59.821	293.50	33.9	-154.6	539.3	1724.1	106.3	55.3	0.2	2467.1
20-30	80.762	341.02	34.0	-154.9	552.3	1799.3	111.5	52.6	0.8	2559.1
20-31	104.762	380.40	37.2	-155.4	569.5	1910.8	120.4	57.6	10.1	2705.0
20-32	111.751	401.15	39.9	-152.2	583.7	1941.4	125.2	61.2	10.4	2761.0

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FINAL GAS COMPOSITION AND BTU

%CO ₂	%O ₂	%N ₂	%CO	%CO ₂	%CO ₃	%CO ₄	TOTAL
1.45	0.00	21.13	70.30	4.53	2.21	.38	100.00

GROSS BTU = 862.

Table B. Example of cumulative volumes of gases released from a coal sample.

Some gas may be lost between the time when a coal is cored and the time when it is sealed into a canister. Although the wireline retrieval method enables the core barrel to reach the surface in only a few minutes, the "lost gas" value cannot be ignored. Reports by the U.S. Bureau of Mines (RI 7767; RI 8043) explain how the initial data can be extrapolated to estimate the amount of lost gas. It is assumed by the Bureau of Mines that a core begins losing gas when the core barrel is half way out of the hole. The rate at which the core releases gas in the first few minutes after the core is sealed is plotted on a graph. The volume of gas lost before the core is sealed is then extrapolated from the graph. Figure D shows a typical lost gas plot.

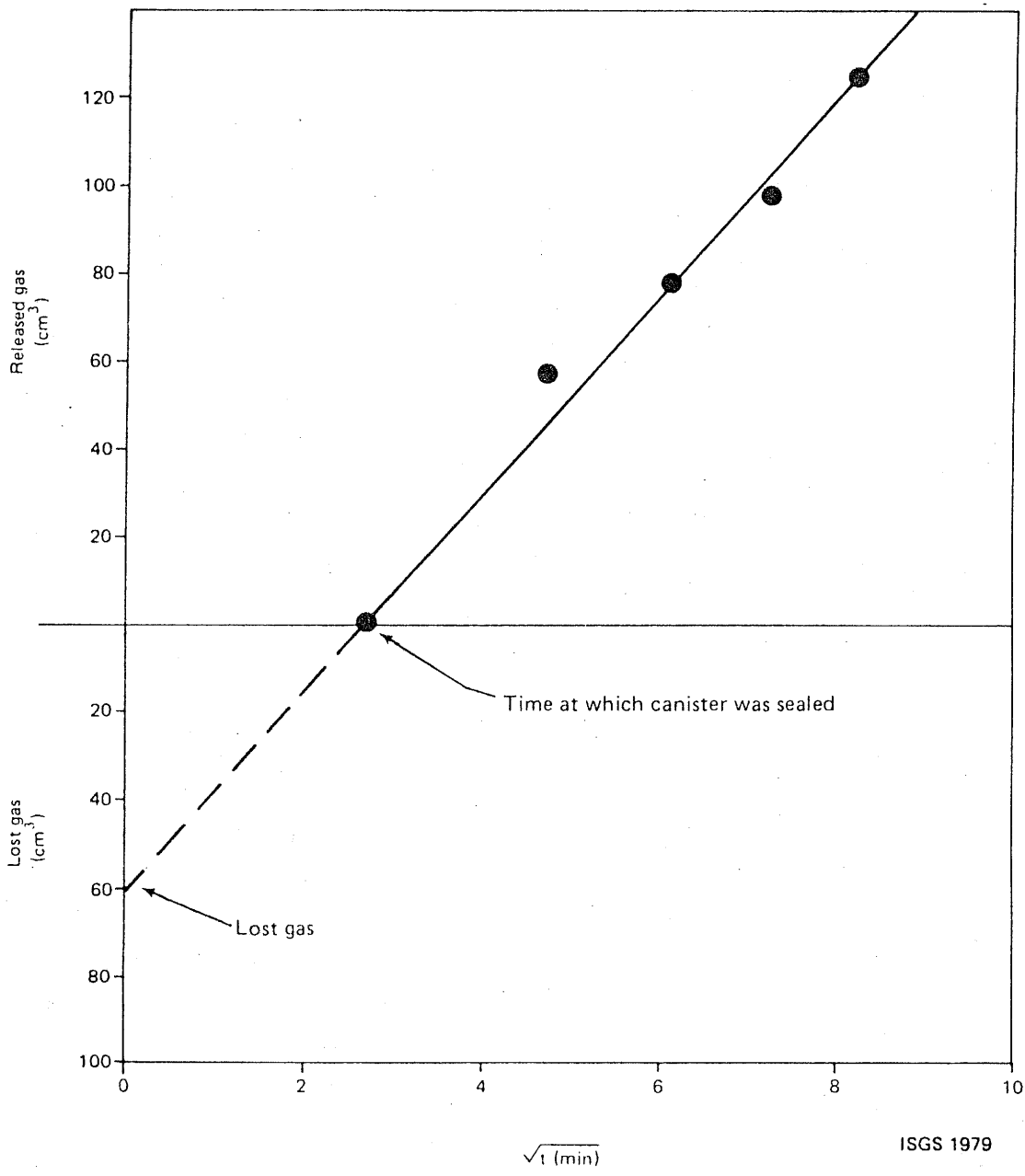


Figure D. Typical plot of lost gas.

The amount of gas released when the coal is crushed is determined in a manner similar to that used to determine the released gas. The volume of each component present at the end of the crushing is determined and the oxygen, nitrogen, and carbon dioxide present in the jar initially is subtracted to determine the amount and composition of "remaining gas". Table C shows an example of the remaining gas determination. We can see that the effects of oxidation are particularly important in determining the remaining gas.

Table C. Sample determination of "remaining gas" desorbed from crushed coal

Coal sample number	20
Amount of coal in jar.	520.6 gm
Amount of coal not crushed	0.0 gm
Amount of coal crushed	520.6 gm
Volume of jar.	1814 cm ³
Volume of crushing media	307 cm ³
Volume of coal	380 cm ³
Volume of headspace.	1127 cm ³
Volume of gas in headspace at STP.	1091 cm ³
Volume of gas bled off as sample at STP.	209 cm ³
Total volume of gas at STP	1300 cm ³

Gas	Sample composition (%)	Gas volume (cm ³)	Air in jar (cm ³)	Volume of desorbed gas (cm ³)	Composition of desorbed gas (%)
CO ₂	.84	10.9	.3	10.6	2.46
O ₂ + A	1.32	17.2	238.7	-221.5	
N ₂	70.88	921.8	852.0	69.8	16.22
CH ₄	20.93	272.2	-	272.2	63.24
C ₂ H ₆	3.53	45.9	-	45.9	10.66
C ₃ H ₈	2.02	26.3	-	26.3	6.11
C ₄ H ₁₀	.43	5.6	-	5.6	1.30
Total	100.00	1300.0	1091.0	430.4	100.00

Note: Amount of remaining gas = 430.4 cm³ ÷ 520.6 gms = .83 cm³/gm.

Appendix F. Isotopic analysis of methane

Samples were prepared for isotopic analyses in a high-vacuum system described by Coleman (1976). Hydrocarbons heavier than methane and carbon dioxide were removed by repeated passage of the gas through a vacuum trap cooled with liquid nitrogen. The methane was then converted to carbon dioxide by oxidation in a copper oxide furnace and collected for isotopic analysis. Isotopic determinations were made on a double-collector mass spectrometer at the University of Illinois Department of Geology. The reproducibility of the δC^{13} values, including variations that may occur during sample preparations, is ± 0.5 ‰.

The isotopic composition of carbon (C^{13}/C^{12}) is expressed as the permil (parts per thousand, ‰) difference from a given standard, where the difference is assigned the symbol δC^{13} (delta- C^{13}). The δC^{13} values are related to C^{13}/C^{12} ratios by the following equation:

$$\delta C^{13}_{\text{sample}} (\text{‰}) = \frac{(C^{13}/C^{12})_{\text{sample}} - (C^{13}/C^{12})_{\text{standard}}}{(C^{13}/C^{12})_{\text{standard}}} \times 1,000.$$

For example, a δC^{13} value of -60 ‰ indicates that the material is 60 parts per thousand (or 6 percent) "lighter" than the standard. That is, the material is enriched in C^{12} by 60 ‰ relative to the standard. More positive values indicate that the sample is less enriched in C^{12} . All carbon isotopic values are reported relative to the internationally accepted PDB standard.

Appendix G. Internal surface area and porosity measurements

A detailed description of the experimental apparatus used to obtain the adsorption data and of the Brunauer-Emmett-Teller (BET) equation used in the calculation of internal surface areas (ISA) is given by Thomas and Damberger (1976). The adsorption of N_2 and CO_2 at $-196^\circ C$ and $-77^\circ C$, respectively, by outgassed samples of coal particles (40 to 120 mesh) is measured by a dynamic sorption method. The internal surface areas are then calculated using the BET equation.

Helium (absolute) densities were measured with He-air pycnometer. Mercury (particle) densities were measured using a 60,000 psi mercury intrusion porosimeter. Prior to density measurements, 6-to 12-mesh samples were outgassed in a vacuum oven at $110^\circ C$ for 18 hours and then cooled to room temperature in a desiccator. The total porosity was calculated from

$$\text{total pore volume (cc/g)} = (1/\rho_{Hg} - 1/\rho_{He})$$

or

$$\text{percent porosity} = \text{total pore volume} \times \rho_{Hg} \times 100.$$

The mercury density used in the above equations was obtained by filling the evacuated porosimeter cell containing the sample with mercury at atmospheric pressure. Pores larger than $120,000 \text{ \AA}$ in diameter are excluded from the porosity calculations

Appendix H. Correcting desorption data for canister leakage

When the data from desorption of the Herrin (No. 6) Coal was entered into the computer to calculate the amount and composition of released gas by the method described in appendix E, it was found that the cumulative nitrogen calculation suggested that nitrogen was being consumed. All other coal samples showed a production of nitrogen. Because there are no apparent chemical reactions that could have caused a significant depletion in nitrogen, the only explanation for the data is that the canister had leaked. The cumulative N_2 calculation involves determining the amount of nitrogen in all samples of gas removed, adding that to the amount of N_2 in the canister, and then subtracting the amount of N_2 originally in the canister. If the rate at which nitrogen is leaking out of the canister is greater than the rate at which N_2 is being released from the coal, the cumulative nitrogen calculation will produce negative values.

Fortunately, the availability of chemical data throughout the desorption process makes it possible to estimate the amount of gas lost through leakage. The amount of CH_4 (C_L) and N_2 (N_L) lost through leakage between any two sample intervals can be calculated by the following equations:

$$C_L = \frac{\Delta C_m - R \Delta N_m}{R/F - 1}$$

$$N_L = \frac{C_L}{F}$$

where ΔC_m and ΔN_m are the measured amounts of CH_4 and N_2 that accumulated in the canister between the two sampling times, R is the ratio of CH_4 to N_2 for the gas released from the coal, and F is the average ratio of CH_4 to N_2 for the gas in the canister during the time in question (i.e., the average CH_4/N_2 ratio of the gas lost through leakage). Similarly, the amounts of the other gases lost through leakage can also be estimated. The only factor in the above equation that is not dependent on measured values is R , the ratio of CH_4/N_2 in the gas desorbed from the coal. The data for the other coal samples studied and data from other natural gas samples from Illinois suggest that the value of R is probably between 2 and 3. Compositions that are based on these values were therefore used to calculate the probable gas content and chemical composition for the released gas from the Herrin (No. 6) Coal shown in tables 3 and 7. Tables D, E, and F show the released gas calculation for the original data, corrected data assuming $R = 2$, and corrected data assuming $R = 3$, respectively. It can be seen that even if the true value of R were slightly outside of this range, the released gas calculations would not be greatly affected.

GAS PRODUCTION DATA

CUMULATIVE GAS PRODUCTION DATA

SAMPLE NO.	TIME (DAYS)	SWRI TIME (MIN)	CO2 (CC)	O2 (CC)	N2 (CC)	CO (CC)	CH4 (CC)	C3 (CC)	C4 (CC)	TOTAL (CC)
17-00	.010	3.74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17-01	.020	5.39	1.0	-12.7	35.2	4.3	.2	0.0	0.0	46.7
17-02	.122	13.27	1.2	-13.0	30.7	10.8	.3	.2	0.0	49.2
17-03	.902	36.04	3.2	-46.1	-70.6	61.8	1.7	.5	.2	67.4
17-04	1.204	41.64	11.0	-83.2	-21.5	315.8	12.2	8.3	1.1	348.4
17-05	1.892	52.19	13.0	-100.4	-45.9	393.7	10.3	9.8	1.5	434.2
17-06	2.919	64.84	16.4	-132.4	-60.3	459.1	20.2	12.5	1.6	509.8
17-07	3.088	74.83	18.3	-141.9	-51.0	514.4	21.5	10.5	2.0	566.8
17-08	4.937	84.31	19.7	-157.3	-40.5	568.5	23.8	12.9	2.1	628.9
17-09	6.944	99.99	24.3	-182.9	-66.0	629.2	30.0	14.7	2.4	700.5
17-10	7.926	106.84	25.0	-198.4	-69.4	674.5	32.7	17.0	2.6	752.5
17-11	11.038	120.07	26.5	-216.1	-93.0	706.7	34.8	18.6	2.8	789.5
17-12	15.923	151.42	29.5	-232.0	-80.5	758.2	40.4	20.0	2.9	851.0
17-13	17.954	160.79	32.4	-240.3	-82.2	774.3	41.8	20.9	3.0	872.3
17-14	39.051	237.14	33.8	-242.2	-73.0	788.4	42.4	21.0	3.1	888.8
17-15	50.965	291.39	34.2	-243.3	-51.4	821.4	42.6	21.8	3.3	923.3

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FINAL GAS COMPOSITION AND BTU

XCO2	XO2	XN2	XCO	XCH4	XC3	XC4	TOTAL
3.71	0.00	0.00	88.90	4.61	2.36	.36	100.00

GROSS BTU = 1056.

Table D. Calculation of released gas for the Herrin (No. 6) Coal using original data.

GAS PRODUCTION DATA

CUMULATIVE GAS PRODUCTION DATA

SAMPLE NO.	TIME (DAYS)	SQRT TIME (MIN)	CO2 (CC)	O2 (CC)	N2 (CC)	C1 (CC)	C2 (CC)	C3 (CC)	C4 (CC)	TOTAL (CC)
17-00	.010	3.74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17-01	.020	5.39	1.0	-12.7	35.2	4.3	.2	0.0	0.0	40.7
17-02	.122	13.27	1.2	-11.1	37.7	16.9	.3	.2	0.0	56.3
17-03	.902	36.04	3.4	-20.4	28.7	66.6	1.9	.5	.2	101.4
17-04	1.204	41.64	11.5	-51.1	106.8	328.0	12.6	8.5	1.1	468.6
17-05	1.892	52.19	14.0	-66.9	129.5	421.9	17.4	10.4	1.6	594.8
17-06	2.919	64.84	18.1	-83.1	150.8	505.3	22.0	13.6	1.8	711.6
17-07	3.888	74.83	20.0	-92.3	169.3	561.1	23.4	11.7	2.2	787.6
17-08	4.937	84.31	21.7	-105.3	188.5	623.8	28.1	14.2	2.3	878.5
17-09	6.944	99.99	27.3	-125.6	213.0	710.0	33.5	16.6	2.7	1003.1
17-10	7.926	106.84	29.2	-139.0	231.1	769.1	36.9	19.2	3.0	1088.4
17-11	11.038	126.07	31.1	-153.1	249.1	830.8	40.5	21.8	3.2	1176.6
17-12	15.923	151.42	34.4	-168.5	267.6	886.8	46.4	23.2	3.3	1261.6
17-13	17.954	160.79	37.5	-176.3	275.1	910.3	48.2	24.3	3.5	1298.8
17-14	39.051	237.14	39.0	-178.2	283.7	924.4	48.8	24.4	3.6	1323.9
17-15	50.965	291.39	39.4	-179.3	305.9	957.4	49.0	25.1	3.8	1380.6

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FINAL GAS COMPOSITION AND BTU

XC02	XO2	XN2	XC1	XC2	XC3	XC4	TOTAL
2.85	0.00	22.16	69.34	3.55	1.82	.28	100.00

GROSS BTU = 822.

Table E. Calculation of released gas for the Herrin (No. 6) Coal corrected for canister leakage using R = 3.

GAS PRODUCTION DATA

CUMULATIVE GAS PRODUCTION DATA

SAMPLE NO.	TIME (DAYS)	SWRT TIME (MIN)	CO2 (CC)	O2 (CC)	N2 (CC)	C1 (CC)	C2 (CC)	C3 (CC)	C4 (CC)	TOTAL (CC)
17-00	.010	3.74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17-01	.020	5.39	1.0	-12.7	35.2	4.3	.2	0.0	0.0	40.7
17-02	.122	13.27	1.2	-10.7	39.3	10.9	.3	.2	0.0	51.9
17-03	.902	30.04	3.5	-10.2	37.0	67.0	1.9	.5	.2	110.0
17-04	1.204	41.64	11.8	-41.0	151.1	337.0	13.0	0.8	1.2	523.5
17-05	1.892	52.19	14.5	-53.8	189.6	436.0	18.0	10.0	1.6	671.3
17-06	2.919	64.84	18.8	-67.2	225.0	520.3	22.9	14.2	1.9	809.8
17-07	3.888	74.83	20.9	-74.8	254.0	587.0	24.5	12.5	2.3	901.7
17-08	4.937	84.31	22.0	-85.9	286.4	650.1	24.5	15.0	2.4	1012.2
17-09	6.944	99.99	28.0	-103.9	329.1	753.2	35.4	17.0	2.9	1167.1
17-10	7.926	106.84	31.1	-115.4	360.0	821.0	39.3	20.5	3.2	1275.5
17-11	11.030	126.07	33.4	-120.7	393.6	893.4	43.4	23.4	3.5	1390.0
17-12	15.923	151.42	37.1	-143.1	420.1	960.2	49.9	25.0	3.6	1501.8
17-13	17.954	160.79	40.4	-150.0	439.0	980.5	51.9	26.2	3.8	1550.7
17-14	39.051	237.14	41.9	-152.0	408.5	1072.6	52.0	26.3	3.9	1575.0
17-15	50.965	291.39	42.3	-153.0	470.7	1035.6	52.7	27.1	4.1	1632.5

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FINAL GAS COMPOSITION AND BTU

%CO2	%O2	%N2	%C1	%C2	%C3	%C4	TOTAL
2.59	0.00	20.83	63.44	3.23	1.66	.25	100.00

GROSS BTU = 751.

Table F. Calculation of released gas for the Herrin (No. 6) Coal corrected for canister leakage using R = 2.

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