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Methane in the Pittsburgh Coalbed, Washington County, Pa.

UNITED STATES DEPARTMENT OF THE INTERIOR

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Methane in the Pittsburgh Coalbed, Washington County, Pa.

By Ann G. Kim
Pittsburgh Mining and Safety Research Center, Pittsburgh, Pa.

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METHANE IN THE PITTSBURGH COALBED, WASHINGTON COUNTY, PA.

by

Ann G. Kim [1]

ABSTRACT

Methane in coal constitutes a serious hazard during mining. Draining the methane from large blocks of coal in advance of mining is an effective method of improving the safety and efficiency of coal mining. Because of the similarity of the two gases, drained methane can be recovered and added to pipeline supplies of natural gas. To effectively apply advance drainage techniques and recover drained gas, a gross estimate of the methane content of coal is necessary. Using data from previous investigations, the virgin reserves of the Pittsburgh coal in the central and southwestern parts of Washington County, Pa., are estimated at over 1.5 billion tons, with a methane content of 50 to 100 ft^3/ton. The Pittsburgh bed in this area of approximately 265 mi^2 contains over 130 billion ft^3 of methane.

INTRODUCTION

The uncontrolled release of coalbed gas into mine workings constitutes a serious safety hazard and growing economic liability. In recent years, although the fatality rate per million man-hours of exposure is decreasing, the percentage of fatalities due to ignitions of methane and to major explosions has increased (26).[2] As coal production from underground workings increases, more reliable degasification techniques must be used to improve mine safety. Dilution of methane with ventilation air to a nonexplosive concentration is currently the most widely used control technique. However, as production increases, the larger quantities of gas emitted from the coal will require larger volumes of ventilation air. There is a practical limit to the amount of ventilation air that can be supplied per unit of time. When this limit is exceeded, production must be halted until the methane concentration falls to an acceptable level. Therefore, other degasification techniques are being developed to supplement ventilation.

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[1] Chemist.

[2] Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

Recent experiments by the Bureau of Mines have demonstrated that draining methane from large blocks of virgin coal in advance of mining substantially reduces the hazard of mine explosions and enhances the efficiency of mining. Drilling drainage boreholes in advance of mining is expensive, and a more immediate return on the necessary investment could be realized by collecting and utilizing the drained methane as a fuel gas. Because of the similarity of the two gases, the drained methane can be used to supplement natural gas as a source of energy. The recovered methane could be marketed as pipeline gas or as boiler fuel. In many instances, it would be economically advantageous for a mining company to use drained gas for plant heating or to operate coal dryers.

The steadily worsening energy situation underscores the need for a systematic investigation of the feasibility of using coalbeds as a direct source of fuel gas. In 1970, primary energy consumption in the United States from all sources was 67.5 quadrillion Btu. In that year, 50 pct of the energy consumed was supplied by coal and gas; 21.4 trillion ft^3 of gas and 599 million tons of coal were consumed. It has been estimated that by the year 2,000 energy consumption will more than triple to 228 quadrillion Btu/year. Although only one-third of this will be supplied by coal and gas, gas consumption will increase to 33.5 trillion ft^3/year, and coal consumption will almost quadruple to 2,333 million tons/year. It has also been estimated that by the year 2,000 economically recoverable natural gas will be depleted by 87 pct in the lower 48 states and by 64 pct in Alaska. At the same time, less than 40 pct of the economically recoverable coal will have been consumed (17).

The gas content of coalbeds is known to be highly variable. Coals at depths of less than 1,500 feet have been found to contain from 0.001 ft^3/ton to 387 ft^3/ton (15-16). Assuming that deeper coalbeds will contain more methane, 200 ft^3/ton is a reasonable estimate for the average gas content of U.S. coals. Minable coalbeds with less than 3,000 feet of cover, excluding strippable coals, contain an estimated 1.3×10^{12} tons of coal and therefore could contain 260 trillion ft^3 of pipeline-quality gas (7). If one-third of this gas was recovered by drainage in advance of mining, the conserved gas would be equivalent to the gas reserves of Alaska. Such methane recovery and utilization presents a number of technical and economic problems. The location and extent of most coalbeds is fairly well known; therefore, exploration costs would be relatively low. However, the gas content of a coalbed can be highly variable, and selecting sites for drainage wells involves some degree of uncertainty. One necessary preliminary step is to obtain a gross estimate of the gas content of virgin coal reserves in order to determine the suitability of an area for drainage in advance of mining. A pilot study of this type was conducted in the Pittsburgh coalbed in Washington County, Pa. This area was selected because its active mines emit significant volumes of gas, its total estimated coal reserves exceed 3 billion tons, and because pertinent data were available from previous investigations. Similar estimates could be made for other areas of the Pittsburgh bed as well as for other coalbeds. Before discussing the estimates of reserves of coal and coalbed gas in Washington County, some general information on gas in coal is given.

COALBED GAS

Coal is a combustible solid formed from plant material by a series of geochemical reactions. During coalification, the percentage of carbon increases, and the percentages of hydrogen and oxygen decrease. As coal metamorphism proceeds, the aromatic character increases with the growth of large condensed-ring systems; paraffinic hydrocarbons, resins, and waxes are incorporated into aromatic clusters (6). The hydrocarbon gases methane through the pentanes are byproducts of coalification reactions, as are hydrogen, water, and CO_2. Possible mechanisms of hydrocarbon gas formation include the removal of alkyl moieties from aromatic molecules, the condensation of straight chain molecules into ring structures, or the decomposition of large alkanoic molecules. In addition to thes mechanisms, methane may be produced by a secondary reaction of gaseous molecules such as the hydrogenation of ethylene and other unsaturates or by the reduction of CO_2. Carbon dioxide formation is attributed to oxidation of organic matter in the presence of occluded oxygen or to decarboxylation of larger molecules. Hydrogen formation is related to the formation of hydrocarbons (23-24).

Because it is porous, coal tends to retain these gaseous products, both as free gas in cracks and fractures and by adsorption on the surface of micropores. The amount of gas within a coalbed is related to pressure, temperature, depth, degree of fracturing, and permeability of adjacent strata. The movement of gas within the coalbed is controlled by diffusion from the micropores, changes in adsorption-desorption equilibria, and laminar flow in cracks and fractures. When coal is removed from the bed, gas emission depends upon the crack and pore structure, size of coal particles, and natural fracture spacing (1, 5, 20).

Although the gas produced during coalification and retained in the coalbed is referred to an methane, it is a mixture of hydrocarbon and inorganic gases. The composition of coalbed gas is not constant; it varies for different coalbeds and for different locations in a single coalbed. Generally, methane is the predominant component, in excess of 80 pct. Ethane constitutes less than 2 pct of the gas along with small amounts of propane, butane, and pentane. Trace amounts of other hydrocarbons have also been detected in coalbed gas. Concentrations of CO_2 and N_2 range from less than 1 to 15 pct; oxygen, hydrogen, and helium may be present. Gas samples taken directly from boreholes in the coalbed do not contain carbon monoxide or sulfur compounds. The calorific value of gas depends upon the relative amounts of combustibles (CH_4, C_2H_6, etc.) and inerts (CO_2, N_2, etc.). Generally, undiluted coalbed gas has a heat of combustion between 950 and 1,000 Btu ft^3, comparable with that of natural gas (14).

REMOVING METHANE FROM COAL

In current ventilation practice, methane drained from the coalbed is exhausted into the atmosphere. Although all mines produce some methane (15), if only bituminous coal mines in the coterminous United States emitting more than 100,000 ft^3/day are considered, 227 million ft^3 of methane is dissipated

in the atmosphere each day. Most of this comes from mines in the Pittsburgh, Pocahontas No. 3, and Illinois Nos. 5 and 6 coalbeds. One mine in the Pittsburgh coalbed produces over 12 million ft^3/day (12). When methane is exhausted with the ventilation air, it constitutes less than 2 pct of the total volume. With currently available technology, it is probably not economically feasible to concentrate this methane to usable proportions.

In Europe, methane drained from coal is often piped to the surface and used as a supplementary energy source. Several methods are used to prevent the gas from entering the mine atmosphere. Boreholes may be drilled into the seam or into the strata above or below the seam. Drainage pipes are sealed into the borehole and the gas flows from the coalbed undet its own pressure or by applying suction to the pipe. Methane is also drained by applying suction to pipes in sealed gob areas and in sealed headings in seams above that being worked. Depending upon the quantity and purity of the gas drained from the coal, it is either exhausted in a return airway or piped to the surface (18, 25). Generally, over half of the drained methane is utilized. In France, 55 pct of the 5.3 $\times$ 10^3 million ft^3 of gas drained during mining was sold in 1967. In Britain, 50 to 70 pct of gas liberated during mining is recovered amounting to over 29 $\times$ 10^3 million ft^3 of gas annually (11). It may be used as pipeline gas or used by the mine as boiler fuel, to heat coke ovens, and for electric power generation (22).

Because of geologic differences, European mining practices may not be directly applicable to U.S. coals. Also, methane drainage during the mining cycle may not be of substantial benefit. The Bureau of Mines is now conducting a drilling program to develop techniques to drain methane from large blocks of coal in advance of mining. Horizontal boreholes drilled from the base of a large multipurpose borehole are being used to degasify a virgin area of the Pittsburgh coalbed in northern West Virginia. Gas flow from the holes has decreased from an initial flow of 900 $\times$ 10^3 ft^3/day to approximately 500 $\times$ 10^3 ft^3/day. In one year, 228 million ft^3 of gas (87 pct CH_4) has been removed from the coalbed (9). In an experiment using vertical boreholes, unstimulated flow from coal and the strata immediately above it produces approximately 5,000 ft^3/day. Hydrofracturing the coal caused a fifteenfold increase in the gas emission rate (8).

PITTSBURGH COAL, WASHINGTON COUNTY, PA.

Washington County (fig. 1) is located in southwestern Pennsylvania, in the northern part of the unglaciated Appalachian plateau. The area is underlain by generally flat-lying rocks of Upper Pennsylvanian and Lower Permian age. Above the Pittsburgh coalbed, which underlies most of Washington County, are alternating layers of sandstone, siltstone, mudstone, claystone, limestone and coal. The area lies on the drainage divide between the Ohio River to the West and the Monongahela River to the east. It is dissected by numerous streams that make the surface hilly, with broad rounded ridges and V-shaped valleys. Maximum relief is about 620 feet; altitude ranges from 900 to 1,520 feet. Most structural features have a general northeastward trend; the synclines and anticlines are broad with gentle dips (21).

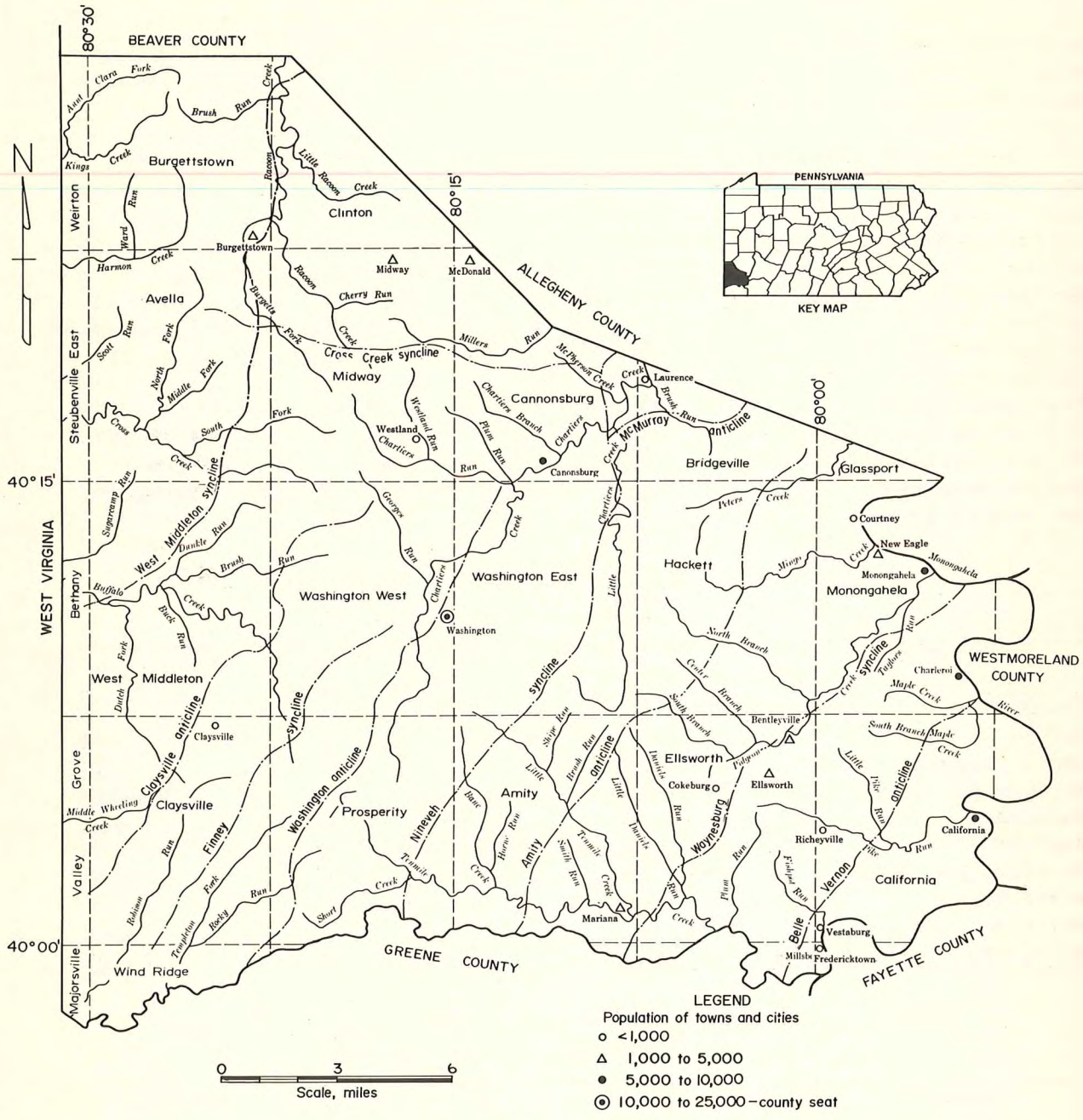

FIGURE 1. - Map of Washington County, Pa.

Above the Pittsburgh coalbed are several coalbeds that outcrop in the Washington County area. The Waynesburg coalbed contains sizable reserves and is mined commercially on a limited scale. The Waynesburg A and Washington coals are locally thick but contain impurities that preclude mining in the near future. The Redstone coal is workable locally, but the Sewickley and Uniontown coals are absent from many areas and are generally thin and irregular. Other coals above the Pittsburgh are also irregular and thin. Several

other coalbeds, including the Upper Freeport and Kittanning, lie below the Pittsburgh coal, but because of their depth, they are not mined at present in Washington County (3, 21).

The Pittsburgh coalbed is the most extensive and currently the most valuable coalbed in Washington County. Remaining reserves are estimated at over 3 billion tons. It underlies most of the county and is absent only in the northwest corner. In Washington County, the Pittsburgh coal outcrops in the northern part of the Burgettstown (15-minute) quadrangle, along the Monongahela River and along several creeks (fig. 2). The Pittsburgh coal generally occurs as two benches separated by a clay parting from 3 inches to 2 feet thick. The lower bench constitutes the main part of the bed. It ranges from 4 to 8 feet in thickness and contains all the minable coal. The upper bench of impure coal ranges from zero to 5 feet and is generally left as roof during mining (3, 21). Average thickness of the coal is 58 inches, with thicknesses ranging from 42 to 90 inches. Depth of cover ranges from zero to 760 feet. Depth of cover and coal thickness for mined and virgin areas are listed in tables 1 and 2.

TABLE 1. - Coal thickness and depth of deep mines in Washington County, Pa. (12)

Mine	Location	Thickness, inches	Depth of cover, feet
Clyde	Frederickstown	50	450-525
No. 51	Ellsworth	70	700
Maple Creek	New Eagle	60	230
Mariana No. 58	Marianna	60	385-413
Mathies	Courtney	42	0-350
Montour 4	Lawrence	52	92-198
Somerset No. 60	Cokeburg	48	450-760
Vesta No. 4	Richeyville	70	0-600
Vesta No. 5	Vestaburg	84	0-500
Westland	Westland	66	0-500

TABLE 2 - Thickness and depth of cover of Pittsburgh coal, Washington County, Pa. (21)

Location	Quadrangle	Coal thickness, inches	Depth of cover, feet
Enterprise	-	60	220
Tylerdale	Washington West	65	277
Cecil Township	Canonsburg	67	230
Midway	Midway	54	50
Cherry Valley	Midway	60	56
S. Burgettstown	Avella	62	275
Venice	Claysville	57	440
Nottingham Township	Hackett	66	600
Pidgeon Creek	Monongahela	72	210
Amwell Township	Washington West	60	350

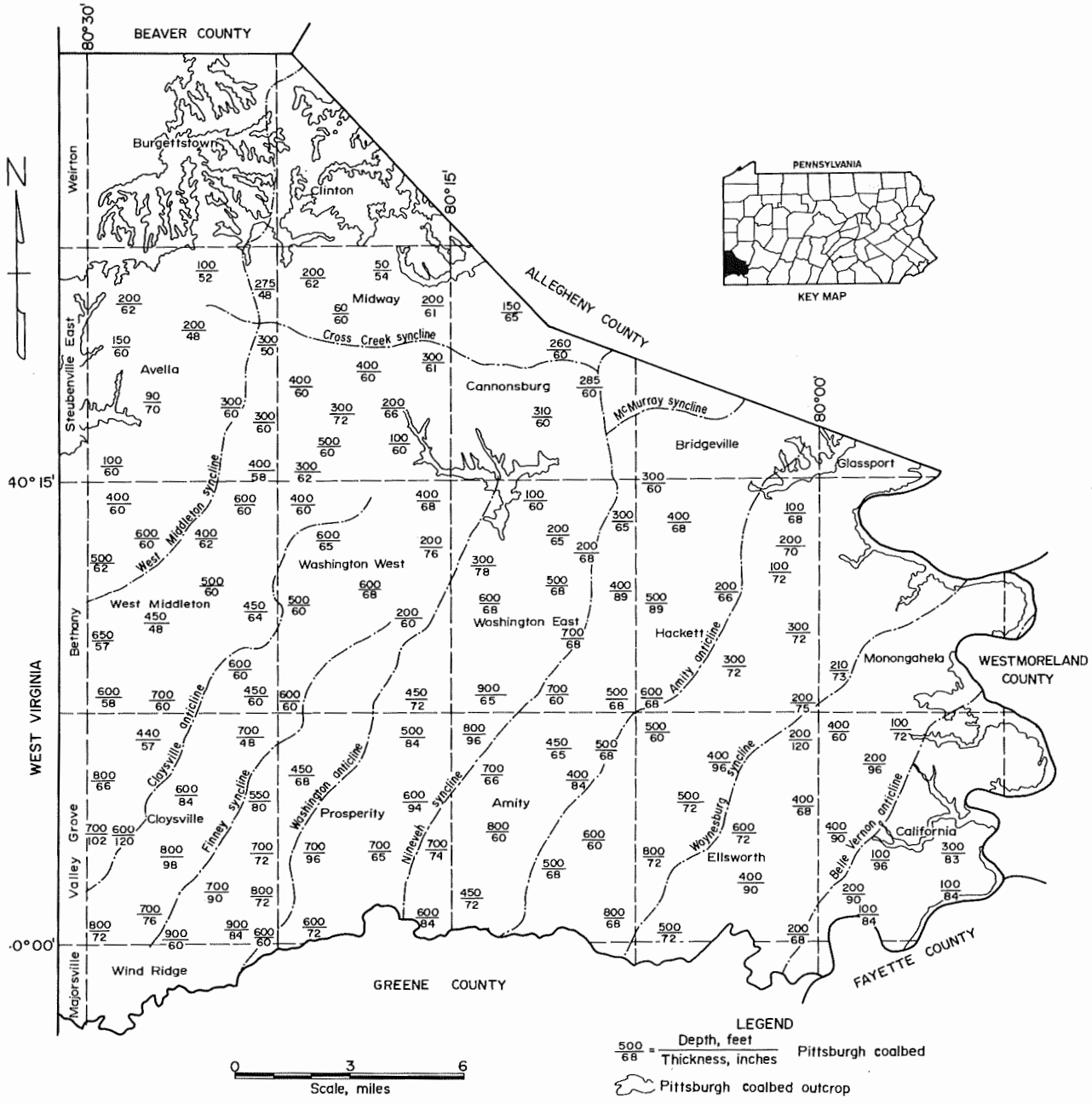

FIGURE 2. - Pittsburgh coalbed, Washington County, Pa.

Coal in the Pittsburgh bed is high-volatile A bituminous and contains an average 6 pct ash and less than 2 pct sulfur. The heating value ranges from 13,600 to 14,800 Btu on an "as-received" basis. Typical analyses for this area are given in table 3.

TABLE 3. - Analysis of Pittsburgh coal from Washington County, Pa.

Mine, location	Moist pct	Ash, pct moisture free	Volatile matter, pct moisture free	Fixed Carbon, pct moisture free	Sulfur, pct	Heating value, Btu
Marianna No. 58,[1] Marianna.....	2.2	12.9	35.2	51.9	1.73	13,130
Mathies,[1] Courtney.....	2.5	9.0	35.7	55.3	1.63	13,650
Westland,[1] Houston.....	3.3	12.0	38.0	50.0	2.84	13,080
Montour No. 9,[2] McDonald.....	3.9	6.8	38.8	54.4	1.8	13,400
Catsburg,[2] Monongahela.....	2.8	6.5	34.5	59.0	1.1	13,870

[1]Gray and Palowitch (10).
[2]Ashley and others (2).

The Pittsburgh bed is currently being mined in both strip and deep mines in Washington County. In 1972, over 380 thousand tons of coal were produced by strip mining in the northwestern part of the country, and deep mines produced approximately 12 million tons (19). Most of the deep mines are located in the northern and eastern section of the county (fig.3). Large areas of virgin reserves are located in the central and southwestern parts of the county.

METHANE CONTENT OF THE PITTSBURGH COAL IN WASHINGTON COUNTY

The amount of methane contained in coal depends upon the adsorptive capacity of the coal, the moisture content, depth of the coalbed, distance from the outcrop, and permeability of adjacent strata. The most reliable method of determining the gas content of a coal is the direct method of Bertrand, Bruyet, and Gunther (4), which involves obtaining a core sample of the coal, placing it in a closed vessel, and measuring the volume and rate of gas desorption. Extrapolation to zero time provides an estimate of the gas lost while obtaining the core. When desorption is complete, the coal is crushed to determine the residual gas. The total of desorbed, residual, and lost gas divided by the weight of the coal sample gives the gas content of the coal. Using a similar direct method, Kissell, McCulloch, and Elder determined the methane content of several U.S. coals. A sample obtained from the Pittsburgh bed in Washington County was found to contain 2.6 cm^3/g or 83 ft^3/ton (16).

The gas content of a coal can also be determined indirectly from its adsorption isotherms. The amount of gas adsorbed in the coal depends on pressure, moisture content and internal structure of the coal. Joubert, Grein, and Bienstock (13) determined the adsorption isotherms for several coals including two samples for the Pittsburgh bed. At 10 atm, Pittsburgh coal with a moisture content of 1 to 2 pct adsorbs between 5 and 6 cm^3 of methane per gram of coal. This is equivalent to 160 to 185 ft^3/ton.

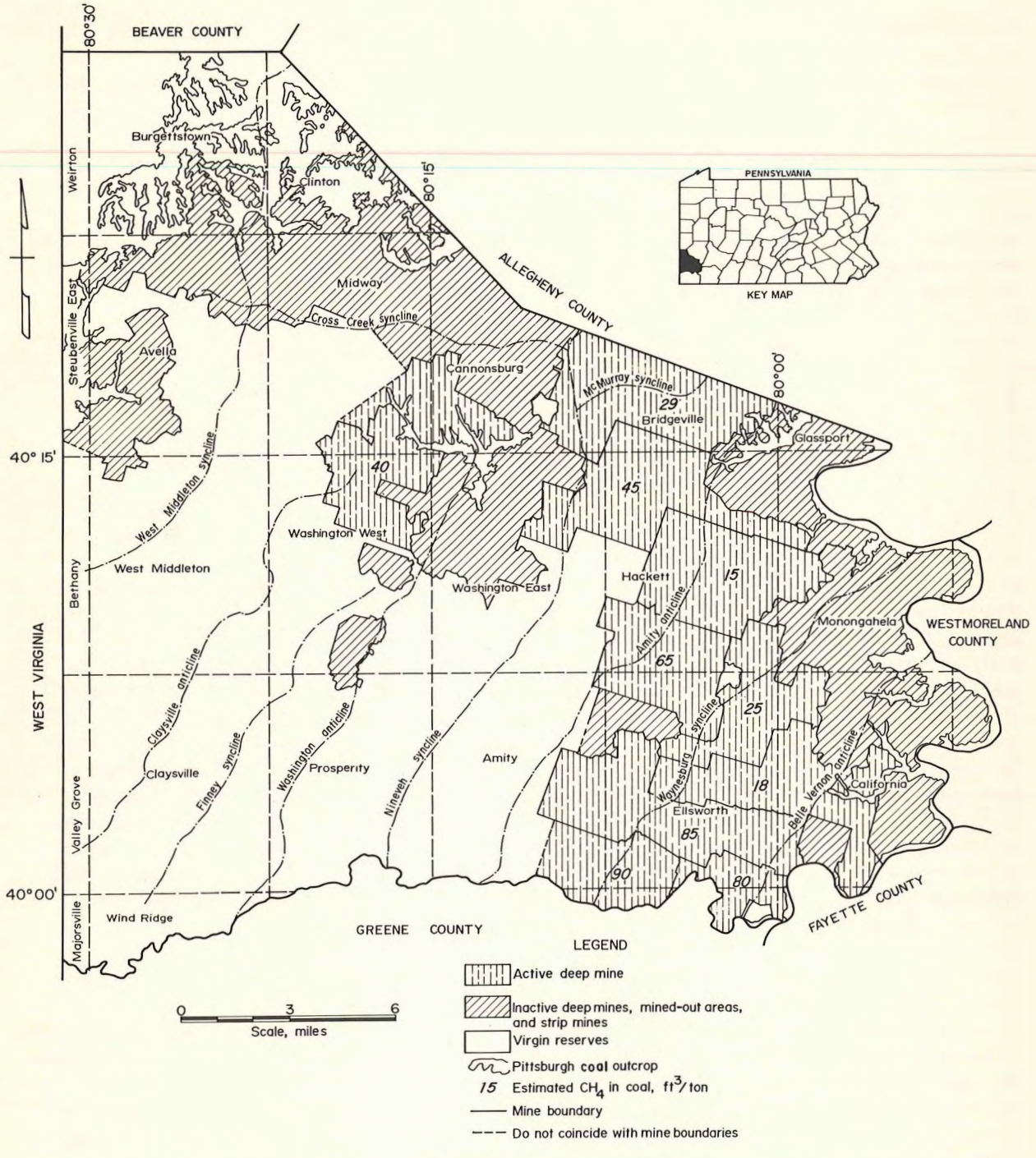

FIGURE 3. - Location of mines and virgin reserves, Pittsburgh coalbed, Washington County, Pa.

Since the adsorption isotherms can be correlated by a langmuir-type equation, the adsorbed volume of gas can be calculated for other pressure values.

Using Joubert's empirically derived correlation constants and the bed pressure of 95 psia obtained from a drill stem test, theoretical values for the adsorbed volume of gas in the Pittsburgh bed, Washington County, were calculated from the equation

$$V = \frac{Vmb^P}{1+b^P}$$

and the results are given in table 4. From adsorption data the maximum adsorptive capacity of the Pittsburgh coal in the Washington County area is estimated at 100 to 150 ft^3/ton.

TABLE 4. - Gas content of Pittsburgh coal calculated from adsorption isotherms

Moist, pct	Vm, cm^3/g	10^2b, atm^{-1}	V, cm^3/g	V, ft^3/ton
1.26	13.3	7.64	4.39	140
1.66	13.4	6.37	3.91	125
2.08	12.8	5.24	3.24	104

Another indirect method of estimating the methane content of coal is based on the methane emission rate (MER) of active mines in the area considered. The MER is determined by monitoring the ventilation exhaust for methane content and total air volume. Approximately 20 to 30 pct of the methane emitted during mining comes from the mined coal; the rest is emitted by ribs, pillars, gob, and reserves. If it is assumed that 20 pct of the MER is contributed by the coal produced and that this represents 80 pct of the methane contained in the coal, the volume of gas contained in the virgin coal can be estimated. Calculated values of methane content for active mines in Washington County plotted on a map of Washington County (fig. 3) show that methane content of the coal generally increases from north to south, from east to west, and with increasing distance from the outcrop. Based on MER derived values, the gas content of the virgin reserves is estimated at 50 to 100 ft^3 of methane per ton of coal.

ESTIMATED METHANE RESERVES

Most of the virgin reserves of Pittsburgh coal in Washington County are located in the southwest quarter. There are extensive areas of virgin coal in the Washington West, Prosperity, West Middletown, and Claysville (7½ minute) quadrangles and along the Pennsylvania-West Virginia border. Substantial reserves are also located in the Washington East and Amity quadrangles (fig. 3). Area and estimated reserves are listed in table 5 (for calculation of reserves, see appendix A).

Assuming that the methane content of the coal increases from northeast to southwest, with depth, and with increasing distance from the outcrop, the amount of methane per ton should equal or exceed that in the coal currently being mined. Values of 60 to 95 ft^3/ton are used to estimate the total methane contained in the virgin reserves (table 5). Using data from table 5,

the total amount of gas contained in the virgin reserves of Pittsburgh coal in Washington County is estimated at over 130 billion ft^3. If only 50 pct of this gas were drained in advance of mining and recovered, it would be sufficient to heat 100,000 homes for 10 years. The gas contained in the Pittsburgh coal in Washington County alone is equivalent to 800 times the natural gas consumed by electric utilities in West Virginia in 1971.

TABLE 5. - Estimated virgin reserves and methane content of Pittsburgh coal, Washington County, Pa.[1]

Location[2]	Estimated area of virgin reserves, acres	Average thickness, feet	Estimated tonnage, 10^6 short tons	Estimated CH_4 content, ft^3/ton	Estimated total methane, 10^9 ft^3
Washington East.....	20,190	5.5	199.9	60	11.94
Bethany.....	4,940	5.0	44.5	80	3.56
Valley Grove.....	4,940	5.0	44.5	90	4.01
Majorsville.....	1,580	5.0	14.2	95	1.35
Wind Ridge.....	7,410	5.0	66.7	95	6.34
W. Middletown.....	35,821	5.0	322.4	80	25.79
Claysville.....	36,333	6.0	392.4	95	37.29
Washington West.....	20,982	5.66	213.8	60	12.82
Prosperity.....	34,800	6.0	375.8	90	33.82
Amity.....	8,648	5.5	85.6	85	7.28

[1]For calculations see appendix A.
[2]See figure 3.

If the complete cost of a drainage hole 600 feet deep is estimated at $12,000 and the wellhead price of gas is estimated at $0.50/1,000 ft^3, a hole would have to produce 24 million ft^3 of gas to pay for itself. This would require that the hole produced at an average flow rate of 25 x 10^3 ft^3/day for 2.6 years and have an effective drainage radius of approximately 625 feet (for calculation see appendix B). Whether a single hole would produce this much gas is questionable. However, when less tangible benefits such as increased safety, greater productivity and decreased ventilation requirements are considered, drainage in advance of mining becomes a more attractive process.

In an experiment conducted by the Bureau of Mines, four boreholes were drilled to degasify in advance of mining a large block of coal in the Vesta No. 5 mine (8). The holes were drilled in a triangular pattern 1,500 feet apart. The 9-inch holes were between 400 and 550 feet deep. During a 4-month period, three of the holes produced 4, 4.7, and 5.1 x 10^3 ft^3 of gas per day. When the coalbed was hydraulically fractured, average gas flow increased to 30 x 10^3 ft^3/day per hole. To date, 10 million ft^3 of gas have been removed from the coalbed. The drained gas is currently being vented; however, as soon as necessary equipment can be installed, the gas will be recovered and added to pipeline supplies, at an estimated rate of 75 x 10^3 ft^3/day.

CONCLUSION

Washington County, Pa., contains extensive reserves of the Pittsburgh coal generally lying 450 to 600 feet below the surface. Extrapolation from data on other areas of the coalbed indicates that the virgin reserves contain 50 to 100 ft^3 of gas per ton of coal. The estimated total amount of gas in the virgin reserves of the Pittsburgh coal in central and southwestern Washington County, an area of approximately 265 mi^2, is in excess of 130 billion ft^3, with an approximate current value of over 65 million dollars. Considering the need to mine coal safely and efficiently and the need to make the best use of all energy resources, methane drainage in advance of mining with recovery and utilization of the drained gas should be included in plans for developing the virgin reserves of Pittsburgh coal in Washington County.

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APPENDIX A.--ESTIMATE OF VIRGIN RESERVES AND METHANE CONTENT

Estimates of areas of virgin reserves are based on a mine map of Washington County, revised April 1971, published by the Pennsylvania Department of Mines and Mineral Industries and on United States Geological Survey 7-1/2-minute quadrangle maps of the Washington County area. For a 7-1/2-minute quadrangle in which there was no past or present mining, the area of reserves was taken to be the area of the quadrangle or 36,333 acres. Other areas were estimated using a grid in which each block equaled 247 acres. Values for coal thickness were obtained from published reports and from drill core data made available to the Bureau of Mines. Average coal density assumed to be 1,800 tons per acre-foot (3). Methane content per ton of coal was estimated by extrapolation from data presented in figures 2 and 3.

An estimate of the virgin reserves and methane content of the Pittsburgh coal in the Washington West quadrangle is as follows:

Estimated area of virgin reserves.....acres..	20,982
Coal density.....tons/acre-ft..	1,800
Coal thickness.....feet..	5.66
Estimated tonnage of virgin areas.....	213.8×10^6
Estimated methane content of coal....ft^3/ton..	60
Estimated total methane.....ft^3..	12.82×10^9

This estimate of virgin reserves is not equal to the total reserves of Pittsburgh coal in Washington County. Not included are reserves above 40° 15' latitude (these are considered too shallow and too near the outcrop to contain significant amounts of methane), nor was the coal in reserves and pillars in active mines included in this estimate. Reserves remaining in mines now closed were also excluded. For this report, estimates of virgin reserves were made only for areas designated in table 5 and figure 3.

APPENDIX B.--ESTIMATE OF COST AND PRODUCTIVITY OF DRAINAGE BOREHOLE

The following calculation is a gross estimate of the economics of using a vertical borehole for methane drainage in advance of mining. Estimates of drilling cost and price of gas are considered reasonable for the present but may change substantially in the future. Productivity figures are based on a hypothetical situation in which the value of the recovered gas is equal to the cost of draining the coal.

Estimated cost of 600-foot drainage borehole (includes equipment, drilling, and hydrofracturing)....dollars..	12,000
Current wellhead price of natural gas....dollars/1,000 ft^3..	0.50
Gas required to recover cost of borehole....ft^3..	[1]24×10^6
Average gas content of coal....ft^3/ton..	75
Coal containing required gas....tons..	320,000
Coal density....tons/acre-ft..	1,800
Average coal thickness....feet..	5
Degasification area....acres..	36
Do....ft^2..	1,568,116
Effective drainage radius....feet..	625

[1]Equivalent to an average gas flow rate of 25×10^3 ft^3/day for 2.6 years.

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