UNITED STATES BUREAU OF MINES
Scott Turner, Director

REPORT OF INVESTIGATIONS

THE OCCURRENCE OF GASES IN COALS

BY

R. F. Selden
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FOREWORD

By George S. Rice

The emission of hydrocarbon gases from coal beds and contiguous strata causes many accidents in coal-mine workings, the number of fatalities so caused being second only to those due to falls of roof. Gases tend to increase in amount with depth of coal mining, hence the danger of explosion is increased with depth. The pressure of the gas in virgin-coal areas at a distance from mine workings likewise tends to increase with depth from the surface, probably due to corresponding increase in hydraulic head and possibly, when the gas is held in nonporous formations, to greater ground pressure. The rise in gas pressure with depth under usual conditions is shown in wells drilled from the surface and in some coal fields in drill holes into the face of workings; however, under normal conditions of coal formation gas does not issue into workings under high pressure because the coal and adjacent strata have many bedding and joint planes which allow the gas to escape freely at

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Report of Investigations 3233."

2/ Assistant physical chemist, Pittsburgh Experiment Station, U. S. Bureau of Mines.

the face of the workings. The rare occurrence of instantaneous outbursts of
gas, with violent effects referred to later, constitute the exception.

Variations of volume and pressure of firedamp or methane found in dif-
ferent coal beds by wells at a distance from mine workings, are analogous to
variations in volume and pressure of natural gas found in different gas and
oil sands, although in general the pressure tends to increase with the depth.
Sometimes, however, in tight sands higher in the formation the pressure of
gas therein is abnormally high, and on drilling the well deeper gas in the
lower strata may be found at lower pressure.

The presence of firedamp in mine air compels the use of multiple paral-
el headings and elaborate ventilating systems and machinery; moreover, special
precautions must be taken to prevent ignition of bodies of explosive gas by
electrical machinery, explosives, and open or defective miners' lights, to
avoid disastrous explosions and fires.

The precautions necessary in gassy coal mines greatly increase the cost
of mining over that in mines virtually free from inflammable gas; therefore
definite experimental evidence and field data which will give information
to those contemplating a specific mining development regarding the poss-
bility of special hazards from gas in a particular coal or bed— or, still
better, which will point a way of lessening the volume and pressure of gas
liable to be encountered in mine workings— would be valuable in protecting
the lives of miners and for obvious economic reasons.

From time to time it has been suggested that in very gassy coal beds it
would be advantageous to drive headings far in advance of room workings for
drainage of gas, but this method is expensive and presents hazards in venti-
lation. It has also been proposed to drill wells from the surface into gassy
coal beds far in advance of mine development to decrease the volume and pres-
sure of gas in the mine workings; in a few instances this has been done, but
the method has not been used generally. In view of a moderate commercial
success in drilling wells to drain gas from the Pittsburgh coal bed in south-
western Pennsylvania and northern West Virginia where mines have not yet been
opened because of the greater depth of shafts required, it is suggested that
well drilling under favorable conditions of quantity of gas and satisfactory
local price for gas might be undertaken systematically before mining is begun
in the locality.

How near to the mine workings it would be advantageous to drill such
wells primarily for gas drainage must depend on the permeability of the strata,
just as this is a factor in the spacing of natural gas wells, but the pressure-
volume gradient curves could readily be determined in each coal field by first
drilling a line of wells, starting from a point near the workings, and re-
cording the pressures and volumes of gas given off in each well.

Although the yield of gas obtained so far from gas wells in the Pitts-
burgh bed has been insufficient to justify the gas companies in putting down
holes at intervals close enough to increase materially safety in mining, royalty
the gas might be waived in some cases by cooperation between the gas company and the owners of coal land. To this end part of the cost of the wells might even be borne by the land owner or prospective mine lessee, to obtain the benefits of increased mine safety and decreased cost of mine development.

In carrying out such a plan it would be highly desirable that when any well has failed to produce a commercial quantity of gas its casing be retained and the top arranged for a vent pipe with a low-pressure check valve. In this way the well might continue to vent small quantities of gas until the mine workings have approached so close to the well that in mines using the exhaust ventilation system it would be advisable to seal the well. One problem connected with such a proposal on which information is desired is whether or not a coal continues to give off or generate gas indefinitely in appreciable amounts.

This and other fundamental facts in connection with evaporation of gases from coal, the conditions of release of the gases, the quantity coming from a virgin area, and the composition of the gases are subjects which have been discussed in the review by Doctor Selden which follows. He has presented impartially the views of coal chemists and mining men of different countries on the occurrence of gas in coal mines and has assembled data from previous laboratory investigations of gas from coal samples and reports of pressure and volume of gas given off in mine workings and, so far as information is available, correlated them with his laboratory investigations.

He has also reviewed many papers and discussions on the occurrence of instantaneous outbursts of gas under high pressures which have had disastrous effects in some instances, but this phenomenon is fortunately confined to only a few mines in a small number of the world’s coal fields. Carbon dioxide is the predominant gas in some outbursts, as in certain coal mines of the Gard Basin, France, and Lower Silesia, Germany. In most instances of outbursts, however, hydrocarbon gases predominate, as in certain mines in British Columbia, South Wales, Belgium, and Czechoslovakia.

One of the fundamental questions in the investigation of the origin of gas encountered in mining in gassy coal fields of simple geologic structure but underlain by gas- and oil-bearing sands is whether all the gas is produced in place in the metamorphism of coal from the lignitic stage to a higher-rank stage or, in part at least, has migrated from lower geologic strata containing petroleum and natural gas through fissures or fault planes into the coal strata above.

The former is the general view, but some advocate the latter theory that the mine gas comes from deeper-seated natural-gas sands and has lost the heavier components by absorption in its migration – to account for the fact that hydrocarbon gas in coal mines is largely methane, whereas natural gas is likely to contain 10 percent more ethane. On the other hand, some natural gas has little ethane.
That gas of different kinds may migrate from lower to upper horizons is indicated by the predominance of carbon dioxide, sometimes nearly pure, in the outburst gases of the Gard Basin and the Power/Silesia field; the origin of carbon dioxide, in these instances it is generally believed, is in underlying limestone strata into which igneous sheets or masses had been intruded. The intrusion cracking the strata above permitted the gases to escape up into the coal beds, which overlie at considerable distance above.

Regarding the composition of firedamp given off from normal coal beds, formerly it was thought that firedamp, free from air, was methane, principally with small amounts of nitrogen and carbon dioxide, but in recent years, with more precise analytical methods, ethane has been found.

A recent German article in Brennstoff-Chemie (June 1, 1932, p. 209) gives analyses of mine gases from certain mines in the Ruhr districts:

<table>
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<th>Colliery</th>
<th>H2 3a/</th>
<th>CH4</th>
<th>C2H6</th>
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<tr>
<td>Mönchen I</td>
<td>2.1</td>
<td>84.9</td>
<td>11.7</td>
</tr>
<tr>
<td>Do. II</td>
<td>1.3</td>
<td>82.7</td>
<td>14.4</td>
</tr>
<tr>
<td>Obernkirchen I</td>
<td>.2</td>
<td>82.6</td>
<td>17.0</td>
</tr>
<tr>
<td>Do. II</td>
<td>.1</td>
<td>68.3</td>
<td>31.7</td>
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Assuming that the component gas proportions shown in these two tables, though varying one sample from another, represent fairly contained or absorbed gases in coal of different kinds, the question naturally arises: Why is the composition of firedamp as it issues into the mine workings not the same as that of gas absorbed in the coal? Is the gas in the coal altered by chemical reaction or are some components absorbed in passing through the open pores and natural cleavage planes and bedding planes of the coal? This is one of the important problems to be solved.

Discussions of some of these questions have been reviewed by Doctor Seiden, and it appears that few precise data are available. Evidently it will require more systematic determination of volume of gas given off under normal geologic conditions from a unit area of a coal bed and precise determination of the character of the component gases.

There are many factors in the problem; among those investigated have been the volume and composition of gases given off from samples of coal crushed in vacuo, the differential absorption of gases, from coal or formed in mine air, the relative permeability of lumps of coal, and the volume of gas given off in different parts of a mine under conditions of regular mining and during periods of stoppage. The character of the gases coming from the face and in mine-air samples has been determined in only a few instances by the precise means of low-temperature fractionation.

3a/ Presence of hydrogen questionable.
With reference to the production of the gases found in coals of different rank, much stress has been laid by many investigators on rock-pressure effects in metamorphism of coal but less on the effect of heating in place, other than by the exceptional instances of igneous intrusions into or adjacent to coal strata. This subject calls for the assemblage of geologic data. Many high-rank coals at one or another geologic period have been buried under strata 5,000 to 10,000 feet or more thick. Most coal fields in the later geologic periods have had much of this cover removed by erosion—for example, in the Appalachian coal fields. On the other hand, the Book Cliffs coal beds of Utah dip under mountain plateaus and in places still have an overburden exceeding 10,000 feet.

At depths of 5,000 or 10,000 feet the ground-temperature gradient reaches 80° to 160° F. above the average surface temperature, or a temperature of 140° to 220° F. in the coal bed. Over long geologic periods such temperatures must accelerate chemical reactions in the coal substance in the metamorphism of the coals to higher rank. As shown by Dr. David White horizontal geologic thrusts, like vertical pressure from depth, have also acted in accelerating metamorphism, as in the production of low-volatile coals such as the Pocahontas and New River coals of West Virginia and the anthracite of Pennsylvania, but whether the metamorphism of these coals is due more to pressure than to heat effects remains a question.

The fact that normal subbituminous coals in the Rocky Mountains have been changed locally by hot lava, intruded in strata above or below the coal but not in contact with it, to the bituminous stage and even to anthracite, as in the vicinity of Crested Butte, Colo., seems to point to the greater importance of heat effects over those of pressure produced either by overburden or lateral thrust.

Evidently much investigation is necessary before these unsettled questions relating to the origin of gases from coal can be answered.
INTRODUCTION

The material in this paper is intended simply to be an inquiry into some of the theoretical aspects of the occurrence of methane and carbon dioxide in coal, with a brief resume of the more recent literature. Several discussions on various phases of the subject have been published, a few of which (4, 20, 25, 88, 30) have more or less extensive bibliographies of the earlier literature. In large measure the pertinent literature deals with the unusual aspects of the subject, and in consequence it might appear that the normal aspects have not been given due consideration here. The latter information is largely a matter of practical field experience, and since that which is normal to one locality is often abnormal to another no sharp differentiation appears to be necessary or, in fact, possible. No attempt will be made to present a critical discussion of the relations between the presence of gases in coal and pertinent geologic features or mining practice.

Although the presence of foreign gases in the ventilating air of many mines is not particularly noticeable, in many others the evolution of methane and perhaps small amounts of carbon dioxide (or sometimes the reverse - large amounts of carbon dioxide with perhaps some methane) is quite apparent.

The presence of small quantities of carbon dioxide can be attributed to oxidation of the carbonaceous matter exposed to the air. In the few cases in which this explanation is not sufficient, obviously the carbon dioxide must escape as such from the coal and neighboring strata.

In a few exceptional mines the evolution of methane is so great (13, 20, 39, 47) - sometimes the weight evolved is equivalent to several percent of the weight of coal mined in the same period - that managements and other interested parties (34, 94) have sought feasible scheme for draining off the gas in advance of the mine workings. As these mines are now worked the cost of diluting the gas evolved with enough air to prevent gas explosions is quite appreciable. Draining off most of the gas would alleviate this expense but would not eliminate it. The potential fuel value of the gas escaping from such mines is another factor worthy of consideration, provided the gas could be drained off without contamination with air. Obviously there is some minimum potential or actual gas evolution below which this drainage could not be profitable as such. It is desirable, therefore, to know something about the possibility of predicting the probable gas evolution by proposed mines or gas wells in a virgin coal bed.

In some restricted coal-bearing regions, where the beds have considerable gas (in which methane and carbon dioxide may be present in comparable quantities or one or the other may predominate) associated with them, phenomena known as "outbursts" (4, 7, 16, 17, 18, 19, 20, 42, 50, 51, 58, 76, 82, 84, 86, 88, 90, 97, 98) occur more or less frequently. In such regions there is an added incentive to drain off the gas, if possible, in advance of the workings.

4/ Figures in parentheses refer to bibliography at end of this paper. Page references are included where different from original citation.

5/ Also correspondence with G. S. Rice.

6/ As will be discussed later the quantity of gas evolved in a mine per unit time is not an absolute indication of the quantity of gas contained in the virgin coal.
To discuss these problems intelligently it becomes necessary to consider the pertinent experimental information available. It is the further purpose of this report to summarize or refer to the available information, and where weaknesses exist to point them out. Because of the meager experimental information now available, a great many diverse ideas and theories pertaining to various phases of the subject are to be found in the literature. This very diversity may be taken as evidence of the complexity of the situation when considered as a whole. Too many of these theories have undoubtedly been based upon very localized experience, yet there may be a semblance of truth in some of them.

ACKNOWLEDGMENTS

The author wishes to acknowledge gratefully the suggestions and constructive criticism of the early drafts of this manuscript by several members of the Bureau staff, notably H. H. Storch, A. C. Fieldner, G. S. Rice, and W. P. Yant. He is also grateful to the mine officials who were instrumental in obtaining the coal samples for the sorption tests and to those who have aided through correspondence.

ORIGIN OF GAS IN COAL BEDS

Although many papers are devoted to discussion of the origin of methane or carbon dioxide in coal beds, no universally acceptable explanation has been forthcoming. Some believe that the gases came from a source foreign to the bed, and some think they were generated within the bed. Some accept one explanation for the one gas and some the other explanation for the other gas. The pertinent experimental facts are still meager, hence it behooves one to approach the matter with some caution regardless of personal opinion and observation.

The methane in coal has been considered generally to be one of the products of the "carbonization" of the organic matter antedating present-day coals. At what stage of the carbonization process the methane was formed, or whether it is not still being formed, are questions which have not been answered satisfactorily. Ralston (73), using data resulting from the analyses of numerous American coals of various ranks, showed by graphical analysis that the principal constituents (carbon, oxygen, and hydrogen) varied in a continuous manner from the lower-rank to the higher-rank coals (24). Hickling (44) has attempted to explain this progressive alteration of the organic matter in coal from one rank to another on the basis of the liberation of carbon dioxide, some water (perhaps), and methane. His study of Ralston's data, augmented by similar data on British coals, led him to the conclusion that carbon dioxide was the principal gas liberated in the carbonization of the lower-rank coals (ignite to bituminous), while methane was the predominant gas liberated in further
carbonization of the higher-rank coals. His view apparently explains the observed alteration in the chemical composition of the various coals having low to high carbon contents. It is not adequate (6, 8) as an explanation of the methane content of the actual gases found in many mines in beds of the lower-rank coals. Possibly in some isolated cases, such as the Gard coal field in southern France, Hickling's theory might suffice (6, 8).

Briggs (6, 8), using the same data as Hickling, has extended the latter's theory in an attempt to explain more satisfactorily the presence of methane in beds of low-rank coals (coals having a carbon-hydrogen ratio of less than approximately 15.3). Both men agree essentially as to carbonization of the higher-rank coals, but they differ as to the lower-rank coals. For the latter Briggs has presented two postulates for the "automatamorphism": (1) The formation of carbon dioxide and methane and no water. (Hickling proposed carbon dioxide, no methane, and perhaps a little water.) and (2) the formation of carbon dioxide and methane simultaneously with the interaction of water and the carbonaceous material. On the basis of the first postulate Briggs claims that the volume ratio of methane to carbon dioxide might be as large as 1 to 2.8. This admittedly corresponds to a lower methane percentage than that actually observed in some mines in beds of low-rank coals. The second postulate permits a somewhat higher methane percentage (perhaps equal volumes of methane and carbon dioxide), but it may be open to objection in that it involves a reaction between water and the coal itself.

Coppens (15) has suggested that carbon dioxide might have been more or less removed from coal beds by solution in subterranean waters or by the formation of carbonates. If this suggestion is plausible and if the cover happened to be rather impermeable to all the gases present in the bed the methane content of the coal would exceed that postulated by theories such as that of Hickling. On this basis the mere fact that low-rank coals often contain more methane than would be expected on the basis of Hickling's theory should not be taken as complete refutation of the theory. Moreover, in some instances where methane was said to be the principal gas evolved by the low-rank coal, reasonable amounts of carbon dioxide may have been overlooked. Hickling's proposal may be more suitable for the lower range of low-rank coals and one of Briggs' postulates more suitable for the higher range of low-rank coals.

7 The evolution of considerable water vapor has been reported for some mines (6, 41) the inference being that some of it comes from the coal.

8 The solubility of methane and carbon dioxide per 100 grams of water at 1 atmosphere and 30° C. is 0.001904 gram (0.03119 mole) and 0.1257 gram (0.00286 mole), respectively. (Landolt-Börnstein Tabellen, vol. 1, 1923, pp. 767-768).

9 As will be discussed later, the composition of the gas evolved in a mine cannot be taken as necessarily equivalent to the composition of the gas contained in the "virgin" coal. It is the latter composition which is of fundamental importance and not the former, irrespective of the supposed source of the gas. If it were experimentally possible to obtain coal samples having gas contents representative of the virgin coals from which they were taken, an extensive study of the amount and kind of gases in coal would yield information of value.
These theories seem to imply that the gases were generated within the coal bed and, further, that gas is being evolved continuously by the present-day coal. In fact, Briggs (8) believes that the persistence of many blowers depends upon this continuous evolution of gas by existing coals. Obviously, if one of these theories, or a slight modification thereof, is truly representative of all the facts the assumption of an exterior source for either gas is not necessary. Davies (21) has pointed out that neither the Briggs nor the Hickling theory offers a satisfactory explanation of the lower ash content of some South Wales anthracites compared with that of the corresponding bituminous coals.

Where considerable methane and carbon dioxide occur together in comparable quantities, it is generally assumed that the carbon dioxide has partly displaced (or diluted) the methane originally present. The portion of the coal field in which such a gas mixture occurs generally separates the field into two parts, one of which contains relatively pure carbon dioxide, and the other relatively pure methane (83).

Wherever carbon dioxide is the principal gas evolved the consensus of opinion seems to support the theory of an exterior source where the gas is supposed to have been generated by intrusions of igneous rock into underlying strata containing limestone (74, 83), or other carbonates. If intrusions always are to be found below coal beds impregnated with carbon dioxide, there are three possibilities: (1) The limestone was decomposed thermally, (2) the carbon dioxide accompanied the igneous rock in its ascent into the upper strata, and (3) the carbon dioxide was formed along with new minerals, by reactions between the carbonates and some of the constituents of the intruded rock. All of these possibilities necessitate retention of the gas in the coal beds and adjacent strata for long periods.

The first possibility is very improbable. It has been estimated that the temperature of intrusive rock at the time of the flow (1, 30, 96) does not exceed 1,000° C. Granting that the mass of the intruded rock is great enough to heat an appreciable thickness of limestone (CaCO3) up to this temperature, the resulting pressure—about 4 atmospheres absolute (58, 45, 92)—presumably is lower than that actually in some coal beds. This assumes that carbonates of elements other than calcium (some of which have higher decomposition pressures at given temperatures) do not exist in large enough quantity in coal-bearing areas to alter this situation materially. In some instances there is evidenee of a purely thermal metamorphism of limestone in juxtaposition to the intrusive magma (57): apparently in all contact metamorphism water may have had some influence.

As far as the author is aware there is no definite evidence for or against the second possibility—that the rock magma contained an appreciable amount of carbon dioxide which it gave up upon cooling in the upper strata.10/ Some geologists believe that the magma had considerable gaseous water entrapped in it at the time of the flow. This belief provides the basis for the third possible explanation of the presence of carbon dioxide in the strata and coal beds adjacent to intruded rock masses.

10/ L. H. Adams of the geophysical laboratory, Carnegie Institute of Washington, has expressed the opinion in a letter to the author that the rock magma does not contribute, of itself, any important quantity of carbon dioxide to adjacent strata.
Leith and Mead, also van Hise, attribute the metamorphic changes in limestones to the action thereon of hot solutions of water and the constituents of the intruded magma (55, 95) rather than to the thermal decomposition of the limestone. Virtually nothing is known about such systems, although probably the pressures of carbon dioxide in equilibrium therewith are greater than the thermal decomposition pressures of calcium carbonate at the same temperatures.

It is well-known that intruded rock sometimes extends under coal beds for considerable areas (8, p. 131). There is no evidence that all the carbon dioxide sometimes existing in adjacent coal beds was generated within the coal bed by the heat dissipated by the igneous rock; in fact, it is only where the intervening strata are too thin to offer enough protection that there is evidence of alteration in the coal as a result of this heat. It is questionable whether or not intrusions always exist below coal beds containing appreciable quantities of carbon dioxide. It is known that intrusions have occurred below some beds containing methane as the principal gas. If limestone was adjacent to the intrusive the carbon dioxide either did not reach the coal or else it was later swept out by methane. Incidentally, if such an instance could be found some information might be obtained as to the origin of the methane.

On the basis of existing data for the scorpion of carbon dioxide by coal and a reasonable value for the gas pressure in the bed (see later sections of this paper), a rough estimate of the amount of gas in a virgin bed at that pressure can easily be made. Thus, if a uniform pressure of 10 atmospheres of carbon dioxide is assumed to exist in the coal bed it appears that the maximum values of the following ratios are approximately as indicated:

Several terms, such as "adsorption", "absorption", and "sorption" (sorbed), have been employed to denote the retention of gases by coal or other materials. Until comparatively recently the first of these terms designated a very definite but postulated conception of the mechanism by which the gas was concentrated by the solid absorbent. Now, however, the accumulated experimental information indicates that what has been thought of as true adsorption is really (in some cases at least) a summation of mechanisms (23) each of which contributes more or less to the concentration of the gas within the solid. Some writers have used the term absorption (26, 79) to denote only the "solution" of the gas within the absorbent; others have included also the possibility of compound formation. Sorption (26, 60, 79) has been used as a sort of all-inclusive term to denote both adsorption and absorption. For the retention of gas by coal "sorption" seems to be the best term of the three because the available information for coal as the sorbent does not warrant the picturization of a detailed mechanism for the concentration of the gas; for this reason the term has been used in this paper. In doing this it may seem that too fine a distinction is drawn between "sorption" and "absorption"; certainly the latter term has been used in a less restricted sense and does present to the laity a picture very similar to that which the term "sorption" is intended to convey.
Weight of coal impregnated
weight of limestone decomposed = 30.

Volume of coal impregnated
volume of limestone decomposed = 60.

The greater the sorption per unit weight of coal, or the greater the loss of gas through the cover, the smaller these ratios become. Insofar as these requirements are comparable with the observed facts the exterior-source theory for carbon dioxide is acceptable.

Herczegh (42) has mentioned a criterion for the presence of methane or carbon dioxide in Hungarian and French coal beds, based upon whether or not the coal-forming organic matter was laid down in fresh or brackish water. This theory implies that the carbon dioxide came from within rather than from without the bed; however, Herczegh cites one instance in which he claims the carbon dioxide was definitely from an external source.

Assuming that an external source of carbon dioxide is the correct explanation in specific instances, one can easily see how the methane if originally present could have been displaced (83, 86). The reverse process would likewise be possible; that is, a continuous supply of methane would displace carbon dioxide from a seam in the same manner.

The external-source theory has been invoked also to explain the presence of methane (14; 39; 83, p. 119) in coal, but it has not been accepted so widely, as it has for carbon dioxide. In general, there appears to be a serious discrepancy between the ethane (and higher hydrocarbons) content of the natural gas, proposed as the source, and the gas derived from coal. Another weakness lies in the fact that no natural-gas fields have been located in the vicinity of many coal-bearing regions containing methane. Although ethane is known to occur in the firedamp of some mines, in most of the reported instances the percentage of this gas is small, and in many of these its presence is somewhat doubtful. Even if it proves to be present in all methane-containing coals, this fact should not be taken as certain proof of an external source, but rather as contributory evidence in its favor.

ETHANE IN COAL AND ITS POSSIBLE RELATIONSHIP TO NATURAL GAS

As has been stated in the preceding section, ethane occurs along with methane in some (perhaps in a great many) mines (15, pp. 312-320; 25; 38; 83). However, the almost complete absence of mines which have reported relatively large percentages of ethane in the evolved gas (comparable to the ethane content of most natural gases) suggests several possibilities:

1. The methane originated within the coal beds along with little or no ethane. (This possibility has been discussed in the preceding
2. The methane now found in the coal beds did not come from a natural gas containing appreciable quantities of hydrocarbons higher than methane.

3. The actual ethane content of the coal is obscured by the greater tenacity with which the ethane is sorbed relative to methane.

4. The ethane was separated out of the inflowing natural gas more or less effectively (by diffusion, with or without selective sorption\(12\)) during its passage through intervening strata or those portions of the coal with which it first came into contact.

Apparently some natural gases contain little or no ethane\(13\), although in the majority of gases found in the United States its percentage is appreciable (10, 11). Hence, if analogies can be drawn between American natural gases and those that might be found elsewhere the second possibility may be correct, although it is rather improbable.

Since the third and fourth possibilities permit the assumption of natural gases containing hydrocarbons higher than methane, obviously there might be some overlapping of these two. For this reason no attempt has been made to draw a sharp distinction between them in the following discussion.

Coal is presumably so far removed from any other material through which the passage of a gas mixture can be mathematically analyzed more or less quantitatively that it may be inadmissible to proffer any suppositions concerning the outcome of diffusion processes therein. However, consideration of those schemes (59, 69, 70) which are suitable for the partial separation of the components of a gas mixture by diffusion processes and which are somewhat analogous to the gas mixture-coal system indicates that a satisfactory separation of the natural-gas constituents during its slow passage through the coal bed would not have resulted. It is possible that some separation took place during the initial state of flow—initial diffusion (70, p. 42) of the natural gas but it is not believed that this situation still exists. Moreover, if, as seems possible, the greater part of the gas has been distributed through the coal-bearing strata by viscous flow through passages many times larger than the molecular mean free path, no appreciable separation would have resulted. In any case, if there has been partial separation in present-day coal beds, the ethane concentration should increase as the points where the natural gas supposedly enters the bed are approached. There is no evidence for such a trend.

\(12\) Selective or preferential sorption occurs when there is no direct proportionality between the sorption of the several constituents of the gas mixture and their respective partial pressures. Incidentally, non-selective sorption seldom occurs, except qualitatively.

\(13\) Burrell and Oberfell (10) cite a case in which gas from two gas-bearing sands, one above the other, was analyzed; the gas from the upper sand showed no ethane, while that from the lower sand contained about 5 percent.
There is no adequate experimental support for this conception of the net effects when a gas mixture flows through coal, although some preliminary results obtained by Greenwald (physicist, Pittsburgh Experiment Station, U. S. Bureau of Mines) and reported by Rice (76) tend to support it. In these experiments the gas mixture was passed through coal dust which had been compressed under a pressure of 20,000 pounds per square inch, and the effluent gas was analyzed periodically to determine its composition. The results are marred by the fact that the gas mixture contained more than two constituents, making interpretation more difficult than it would have been otherwise; however, they do show a distinct separation of the principal components—carbon dioxide and methane—during the period of initial flow (presumably due partly to selective sorption and partly to diffusion effects). Moreover, after the flow had continued for some time the effluent gas did not differ greatly in composition from the entrant gas. It is true that the final effluent gas apparently did not contain as much ethane as the original gas, but it is significant that a good fraction of it did pass through. It is believed that the changes in composition noted in the latter part of the experiment can be explained more satisfactorily on the basis of selective sorption than on the basis of different diffusion rates.

Regardless of whether or not diffusion processes have led to any separation of the natural-gas constituents the preferential sorption of ethane (which undoubtedly occurred to some extent and which further complicated any possible diffusion) would have led to degradation in the ethane content of the coal, just as has been supposed for diffusion. If the sorption of ethane is decided preferentially then the gas evolved in the mines would have a very much lower ethane concentration than did the actual gas with which the coal at that point was originally impregnated. Conversely, if the ethane is more or less uniformly distributed in a bed at present there appear to be only three possibilities:

1. The rate of the gas flow through the bed was extremely slow.

2. An almost infinite time has elapsed between the time of the flow and the present. (This cannot be true if gas has been flowing continuously and at an appreciable rate from the coal beds.)

3. The gas was distributed primarily by viscous flow through fissures.

The sorption of ethane may not exceed that of methane, at equal partial pressures, by a factor of more than about 6 to 10; in all likelihood it is less. Perhaps the higher ethane concentrations in the coal near those points where the natural-gas seepage supposedly enters the bed can be verified experimentally; or, since these points probably cannot be located very readily, the variation of the ethane content, if any, might indicate the proximity of such points. Some care would have to be exercised in collecting such data. Certainly the composition of the gas evolved in mines cannot be taken as an absolute index. A combination of such data with those on the composition and quantity of gas remaining in the coal might be satisfactory. Even this method would have to be applied with great care.
While small amounts of ethane may have been overlooked in coal mines, one can be reasonably certain that if ethane had constituted as much as 10 percent of the gas evolved, as it often does with natural gas (10), it would have been reported more often and in greater quantities. Even assuming that the ethane might have been more or less separated out as the natural gas seeped through the bed, it seems very odd that more mines have not been worked which were close enough to the natural-gas entrance points to show considerable ethane.

On the basis of these suppositions one would expect to find in the coal removed in mining a larger fraction of the ethane than of the methane present in the virgin seam before mining operations were initiated. Graham (36) states that where ethane was indicated in firedamp the methane evolution was comparatively small; that is, the greater part of the methane had escaped prior to the mining operations. If this partial separation is observable after long periods, as this observation implies, then it certainly should be noticeable for the shorter period covering the life of the mine or a fraction thereof.

In this connection grinding the coal in vacuo (78) might furnish interesting information as to the actual amount of ethane remaining in coals. As an alternative method one might extract the coal with a suitable solvent in a closed apparatus. This method would be applicable only if all the gas could be recovered readily from the solvent and if no gas resulted through decomposition of the coal constituents by the solvent.

The fraction of the original ethane content that would appear in such experiments would depend partly upon the character of the coal and neighboring strata. The value of such information would be limited by the accuracy with which this fraction could be determined; hence one may question the advisability of applying the method to existing gassy mines. In the latter, suitable information on the composition of the gas which has already escaped does not exist. Moreover, the question of what fraction of the gas escaping into a given mine comes from relatively great distances beyond the coal face is still unsolved. One must know something about the rate of flow back of the face and the composition of this gas before a given case can be analyzed.

The ideal procedure would involve determination of the pressure and composition of the gas derived from a series of wells sunk to the virgin coal bed and the amount and composition of the gas contained in the coal itself (such as cores). Most of this information might also be obtained from recently opened mines at strategic points.

Fisher (25) has cited two German coals whose ethane content was great enough to correspond favorably with that of some natural gases (10), provided the original coal contained a reasonable amount of methane. (This assumes that the ethane and higher hydrocarbons were not due to any decomposition of the organic matter in the coals at 100°C. or to localized heating resulting from the impacts in the ball mill.) Conversely, Fisher found

14/ Suggested by H. H. Storch, physical chemist, Pittsburgh Experiment Station, U. S. Bureau of Mines.
the ethane content of other coals so small that it is difficult to see how the gas, which might have impregnated the bed originally in the locality considered, could have contained much more than a trace of ethane. This does not follow, of course, if the major part of the original ethane had escaped, with the methane, before the tests.

Coppens (15, pp. 312-320) has analyzed a great many samples of gas, obtained from mines in several Belgian coal fields, by a modified low-temperature fractionation method. Ethane (or higher hydrocarbons) was indicated in every gas examined, the maximum percentage being 2.79 and the minimum just a small fraction of 1 percent. Very small amounts of hydrogen were also reported in a few samples.

So far as the author is aware, the low-temperature fractionation method has been used only twice in the United States for analyzing the hydrocarbon content of a gas sample collected in a coal mine. It so happens that the presence of a small amount of ethane was indicated with reasonable certainty in both instances. Admittedly, there was good reason for suspecting higher hydrocarbons in both cases before this mode of analysis was applied.

A New Mexico17/ gas was found to contain:

| Bottle no. | - - - - - - | 465 | 468 |
| CH₄ | - - - - - - percent | 3.30 | 2.00 |
| C₂H₆ | - - - - - - do. | .26 | .26 |
| C₂H₅ (based upon CH₄ plus C₂H₆) | - - - - percent | 7.3 | 11.6 |

16/ Apparently P. Lebeau (34) and the Helium Division of the Bureau of Mines (referred to later) were among the first to employ this method for determining ethane in firedamp.

17/ Two samples of this gas were collected in the Phelps-Dodge Corporation no. 6 mine, Dawson, N. Mex., the gas being peculiar in that it had an odor resembling that of gasoline. (See also Graham, J. I., and Skinner, D. G., Note on the Composition of Oil Found in Proximity to Certain Coal Seams of North Staffordshire in Relation to Its Mode of Formation: Trans. Inst. Min. Eng., vol. 73, 1926-27, p. 349). The gas samples were analyzed by the Helium Division of the Bureau of Mines in June 1924.
The composition (100) of a British Columbia\(^{18}\) gas was found to be:

<table>
<thead>
<tr>
<th></th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{CO}_2)</td>
<td>3.5</td>
</tr>
<tr>
<td>(\text{O}_2)</td>
<td>19/0.0</td>
</tr>
<tr>
<td>(\text{N}_2)</td>
<td>19/0.0</td>
</tr>
<tr>
<td>(\text{CH}_4)</td>
<td>96.27</td>
</tr>
<tr>
<td>(\text{C}_2\text{H}_6)</td>
<td>0.21</td>
</tr>
<tr>
<td>(\text{C}_3\text{H}_8)</td>
<td>20/0.02</td>
</tr>
<tr>
<td>Higher</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Total volume of gas fractionated—---477.5 cc.

This gas was first fractionated and the proper fractions were then subjected to combustion analysis to confirm their identity. The absence of air would indicate that the small amount of carbon dioxide was a constituent of the gas evolved by the coal and not due to "black damp."

The presence of ethane in coal from the Coal Creek mine was confirmed (100) further by an analysis of the gas that came off the moistened coal when it was ground at room temperature in a ball mill (78) under a pressure of 20 to 30 mm (that is, approximately the vapor pressure of water). The composition (by combustion-absorption method with an Orsat apparatus) and quantity of gas evolved by two samples on an air-free basis are given in table 1.

---

\(^{18}\) This sample was described as being taken by B. Canfield, superintendent of Crows Nest Pass Co., from face of no. 2 crosscut, room 16, east slope, No. 1 East mine, Coal Creek, British Columbia, after blow-out of gas on Nov. 5, 1926. The gas was obtained (in vacuum collecting tubes) at a point about 6 feet back from the face and where it was freely issuing from a crevice on the right side of the rib, extending into and upwards from about midway between floor and roof timbers.

\(^{19}\) Sample did not contain air.

\(^{20}\) Somewhat "doubtful."
Table 1. - Composition and quantity of gas evolved by grinding coal from Coal Creek Mine

**Sample 1**

<table>
<thead>
<tr>
<th>Gas pumped from uncrushed coal as received</th>
<th>Additional gas pumped off after grinding under reduced pressure</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (N.T.P.) per 100 grams, cm³</td>
<td>Percent</td>
<td>Volume (N.T.P.) per 100 grams, cm³</td>
</tr>
<tr>
<td>CO₂</td>
<td>39.6</td>
<td>24.3</td>
</tr>
<tr>
<td>CH₄</td>
<td>85.0</td>
<td>52.0</td>
</tr>
<tr>
<td>C₂H₆</td>
<td>5.6</td>
<td>3.4</td>
</tr>
<tr>
<td>N₂</td>
<td>32.8</td>
<td>20.3</td>
</tr>
<tr>
<td></td>
<td>163.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

**Sample 2**

| CO₂ | 32.0 | 17.1 | 5.5 | 15.3 | 37.5 | 16.8 |
| CH₄ | 78.3 | 41.9 | 9.9 | 27.4 | 88.2 | 39.6 |
| C₂H₆ | 7.1 | 3.8 | 9.9 | 27.6 | 17.0 | 7.6 |
| N₂ | 69.5 | 37.2 | 10.7 | 29.7 | 80.2 | 36.0 |
| | 155.9 | 100.0 | 35.0 | 100.0 | 222.9 | 100.0 |

1/ Sample 1 - coal taken from face of No. 2 crosscut, room 16, east slope, No. 1 East mine, Coal Creek, British Columbia. Taken after an outburst of gas and coal on Nov. 5, 1926. Collected close to cracked rib where gas was given off.

Sample 2 - coal taken from same place as sample 1 but back of rib side in hard, knotty coal that usually precedes a blow-out of gas.

2/ All volumes are corrected to 0°C. and 1 atmosphere, that is, normal temperature and pressure (N.T.P.).
Before this work the presence of ethane in the British Columbia coals had been reported by Fieldner (78).

Suppose that the ethane in the natural gas which might have passed into a given coal bed was not distributed as readily as the methane with respect to the point of entrance and that the few instances in which ethane constitutes a fair fraction of the gas in the coal represent localities in which the ethane percentage has been increased due to this unequal distribution. Then one cannot presuppose a very great flow of natural gas in the past without acknowledging that the original natural gas with which the bed was impregnated must have contained rather small amounts of ethane. If not, then the fraction of the bed in which considerable quantities of ethane exist in the coal must be larger than it is now believed to be, or else the major part of the ethane that was separated out from the methane must remain stored in undiscovered spots.

Other investigators have reported ethane in coal-mine firedamp (38), but in most of these investigations it is believed that the combustion-absorption method of analysis21 was employed.

RETFENTION OF GAS BY COAL

Several theories have been proposed to explain how gases are stored in coals. The only one that seems to have a sound experimental as well as theoretical foundation involves the idea of "adsorption", "absorption", or "sorption." Some authors prefer or at least use the term "adsorption." It has the objection of implying a preconceived structure for the coal; that is, the coal is thought to contain a great many submicroscopic capillaries or pores similar to those in charcoal. There does not seem to be any good reason (other than the fact that it does sorb gases) for believing that coal has such a structure; certainly there is no microscopic evidence for it. Of course, if one wishes to extend the capillary idea to the point where virtually all the gas is held in capillaries having "diameters" of the same magnitude as the various molecules in the coal there can be no particular obiec-

21/ This method of analysis is theoretically capable of being used for the analysis of a mixture of methane and ethane, but it is questionable whether the average analyst can report, with certainty, the presence or absence of ethane when the total hydrocarbon content (most of which is methane) of the original sample was relatively small, as is generally the case with mine air. If, by a suitable collection procedure the sample should contain a large percentage of methane, possibly with some ethane, it again becomes difficult to determine with certainty small quantities of the latter constituent. Where the combustion method indicates several percent of ethane there can be little doubt about its presence, although the exact percentage indicated may be somewhat in error.

In view of the intrinsic difficulties and limitations of the older analytical method it would seem that the low-temperature fractionation method offers distinct advantages where knowledge of the quantities of higher hydrocarbons is desirable.
tion to the term "adsorption." Since coal contains molecules of various
degrees of complexity (all of which are probably not crystalline) it is possi-
ble that some of these exist as very viscous liquids. We might question the
use of the term "solution" for the sorption of gases by such aggregates be-
cause of the relative immobility of the sorbent molecules. There is no con-
cclusive evidence for or against the possibility that a small amount of mobile
liquid exists in coals - if it does exist, a small and probably inconsequential
portion of the gas sorbed by the coal can exist in true solution.

Gaeger (29) has attempted to estimate the size of the capillaries in
coal, but as has been pointed out by Storch (29) in his written comment on
Gaeger's paper, and by McBain elsewhere (52), the assumption of capillaries
of almost molecular size presents a picture little different from that of a
solid solution. According to Thiessen (research chemist, Pittsburgh Experi-
ment Station, U. S. Bureau of mines) there is no microscopic evidence, even
at high magnification, for any appreciable number of free spaces in coals.
Some of these observed undoubtedly result from the unpreventable removal of
some mineral matter during preparation of the slides. A few cavities (which
he said looked like "gas bubbles") are sometimes seen in the resinous matter,
but on the whole the volume (or surface) represented by these spaces is said
to be negligible.

Huff (66) seems to prefer the idea of true solution to that of adso-
ration for both carbon dioxide and methane in coal, although in an earlier
paper (68) no particular distinction was made between the two mechanisms.
Rudolph (84) treats the problem as if both adsorption and solution phenomena
were active in retaining the gas in the coal, especially at the higher pres-
stures. The curve for the solubility of methane in some of the lower hydro-
carbons (28) does not flatten out at the higher pressures (up to 100 atmos-
pheres Henry's law is approximately valid). As will be shown later, the
curves for the sorption of both carbon dioxide and methane by coal bend con-
siderably more toward the pressure axis. The adsorption curve for methane
on charcoal (27, 35) does likewise, but the volume of gas held at saturation
(if saturation in the usual sense is possible with either coal or charcoal)
is of a greater order of magnitude than for coal. However, this similarity
in the methane sorption and adsorption curves for coal and charcoal, respect-
ively, does not necessarily indicate exactly analogous gas-concentration
mechanisms.

If most of the gas sorbed by coal is held within the interior of each
particle of coal the effect of grinding the coal will be observable only if
the increase in adsorptive surface produced thereby is appreciable compared
with the postulated "interior surface" of the coal; that is, the surface of
the submicroscopic pores, capillaries, and interstices. The results of
Graham (33) may be said to support the view that the increase is not very
great. He found that "The process of breaking up the coal in the laboratory
does not, therefore, produce an increase in the adsorptive capacity of the
material at all proportionate to the increase of surface area as calculated
from the number of particles into which the larger lumps have been broken."  
Huff and Ascher (87) conclude from their results that "The ability to absorb
carbon dioxide is almost the same for powdered coal as for lump coal."
Another theory has been proposed to explain retention of the "latent" gas in coal (13), but just what its physical significance may be is rather uncertain. The attainment by any appreciable quantity of coal of the distillation temperatures postulated seems unlikely on the basis of a reasonable value for the specific heat of coal and the available energy from roof settlement. Although vague, this theory appears to resemble the old chemical compound theory—that is, the production of a fixed gas pressure for a given coal sample placed in a gas-tight space led some to postulate a definite compound or series of compounds of methane (85). The fact that this equilibrium pressure will decrease continuously as the gas is removed from the confining vessel disproves this conception. Moreover, a similar postulate would have to be made for carbon dioxide in coal, as Sim has pointed out (90).

The possibility of all the gas existing as such in any submicroscopic cavities in the coal can be shown to be highly improbable by some simple considerations. To take a very conservative instance—that is, one that will give a maximum of voids and hence require a lower gas pressure—assume that the matter in a low-density coal \( d = 1.3 \) has an actual density corresponding to a rather high-density graphite \( d = 2.6 \), whence the voids would equal one half the total volume of the coal. Evolutions of considerably more than 1,500 cubic feet of methane per ton (13; 39; 47; 78, p. 539; 30; 93) — 25 cubic feet of coal weighs approximately 1 ton — of coal mined probably are uncommon but certainly are not unknown. While it cannot be said that all of this gas must come from the coal broken down in mining (9, 47), it is believed that a good fraction of it often does, unless a large part of the coal is left underground. One coal sample (see tables 1 and 2) has been tested (48) in the laboratory and was found to give off, at room temperature and under a partial vacuum (25 mm, approximately), about six times its own apparent volume of gas after being removed from the mine. This indicates that the minimum pressure in the coal, assuming that all the gas existed therein as such, was not less than 12 atmospheres absolute. Grant (36) has reported an anthracite that gave off a somewhat greater relative volume of gas, necessitating the assumption of still higher initial pressure.

If one takes the densities determined with mercury and helium instead of these density values, the void space probably would not exceed 10 percent of the apparent volume of the coal compared with the 50 percent cited above (89). The smaller porosity thus leads to absurd pressures for the gas unless the sorbed gas is more dense than it is in the gas phase under corresponding conditions. If this were not so, the required pressures could not in general be counterbalanced by the thrust of the cover. The vertical thrust of the cover amounts to about 1 pound per square inch per foot of depth (7), and unless the vertical component of other forces augments this somewhat (which does not seem possible over great areas) a cover of 1,500 feet would be necessary to withstand gas pressure of about 100 atmospheres.
GAS CONTENT OF COALS

The composition and amounts of gas derivable from various coals under diverse conditions, and the rates at which they are evolved, have been investigated in a few instances (12, 78, 26, 48, 65, 71, 72). In most of these the published information is unsatisfactory in one respect or another. In general, investigators have reported only data which concerned the particular problem under investigation. Hence pertinent information, such as the length of time the sample was exposed to air after removal from the mine, screen and chemical analyses, and character of the coal has been partly omitted in most investigations. Moreover, the heat treatment (1000 C. generally) sometimes employed to hasten the evolution of the gas might be open to objection from the standpoint of this discussion, although not, perhaps, from the standpoint of the investigation concerned.

Qualitatively, the amounts and kinds of gas evolved by coal samples might be related more or less to the rank of coal or the amount of weathering it has undergone, but it is improbable that such results can be used to draw analogies as to the gas composition and content of the virgin bed. Unless the composition of the gas evolved by the coal remained the same from the time the gas first started to drain from the coal until the coal was received in the laboratory (which does not seem very probable), obviously the initial and final gas composition cannot agree. Likewise, the gas evolved by lumps of coal under usual laboratory conditions is not indicative of the actual composition of the gas remaining in the coal. Thus, several cases are on record (78, 33, 48, 91) in which ethane was evolved by powdered coal in a vacuum, whereas little or no ethane was evident in the gases evolved by the less finely divided coal under higher pressure.

Most of the reported work on the gases in various coals is reasonably accessible and will not be reviewed here, since virtually none of it, without auxiliary data, has much value from the standpoint of this paper. However Kembel's unpublished results (48) have enough interest to merit their inclusion as tables 2 to 5. The absence of a detectable amount of ethane in the gas pumped from small lumps of coal (table 2) as compared with its presence in the gas evolved by the same but more finely divided coal (table 3) shows clearly the effect of particle size upon the ease with which this gas escapes.

After the data in table 2 had been obtained some of the coal, with twice its weight of water, was placed in a special ball mill (78) and ground under partial vacuum (initially the vapor pressure of water). After the coal was ground for the desired time, the gas in the mill was removed with a Toeppler pump, and its volume and composition were determined with an Oregot apparatus. For comparison, another sample of coal from the same mine was ground in the same manner but not given the preliminary pumping treatment. The results obtained with these two samples are listed in table 3. The second sample contained much less gas upon arrival than did the "outgassed" sample. The latter must have been exposed for a shorter time and hence lost less of its original gas. There is no reason for believing that the original gas contents of the two samples could have differed by the factor indicated.
### TABLE 2. - Amount and composition of gas released by 4,620 g of Pittsburgh coal (no. 4 bed, Consolidated Coal Co. mine no. 261) upon evacuating 1⁄2-inch lumps at room temperature

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Volume of gas (N.T.P.) removed by pumping 4,620 grams coal</th>
<th>Volume of methane, cm³ (N.T.P.)</th>
<th>Interval over which gas was collected, days</th>
<th>Composition (air free) of gas increments 3/ percent</th>
<th>Total volume of methane, cm³ (N.T.P.) per 100 grams of coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>4,720</td>
<td>3,420</td>
<td>(4)</td>
<td>0.7 72.5 26.8</td>
<td>74</td>
</tr>
<tr>
<td>3</td>
<td>5,340</td>
<td>5,290</td>
<td>0</td>
<td>3 99.1 .6</td>
<td>189</td>
</tr>
<tr>
<td>4</td>
<td>1,620</td>
<td>1,500</td>
<td>5</td>
<td>3 98.7 6/1.0</td>
<td>223</td>
</tr>
<tr>
<td>5</td>
<td>1,330</td>
<td>1,330</td>
<td>10</td>
<td>4 99.6 ---</td>
<td>252</td>
</tr>
<tr>
<td>6</td>
<td>1,110</td>
<td>1,100</td>
<td>18</td>
<td>4 99.6 ---</td>
<td>276</td>
</tr>
<tr>
<td>7</td>
<td>700</td>
<td>700</td>
<td>23</td>
<td>5 99.5 ---</td>
<td>291</td>
</tr>
<tr>
<td>8</td>
<td>600</td>
<td>600</td>
<td>25</td>
<td>6 99.4 ---</td>
<td>304</td>
</tr>
<tr>
<td>9</td>
<td>630</td>
<td>630</td>
<td>27</td>
<td>6 99.4 ---</td>
<td>317</td>
</tr>
<tr>
<td>10</td>
<td>830</td>
<td>810</td>
<td>35</td>
<td>5 97.3 2.2</td>
<td>335</td>
</tr>
<tr>
<td>11</td>
<td>680</td>
<td>670</td>
<td>42</td>
<td>7 98.3 1.0</td>
<td>350</td>
</tr>
<tr>
<td>12</td>
<td>840</td>
<td>810</td>
<td>55</td>
<td>7 96.9 2.4</td>
<td>367</td>
</tr>
<tr>
<td>13</td>
<td>710</td>
<td>690</td>
<td>69</td>
<td>9 96.7 2.4</td>
<td>382</td>
</tr>
<tr>
<td>14</td>
<td>450</td>
<td>440</td>
<td>91</td>
<td>1.0 96.8 2.2</td>
<td>391</td>
</tr>
<tr>
<td></td>
<td>520</td>
<td>500</td>
<td>107</td>
<td>1.2 96.1 2.7</td>
<td>402</td>
</tr>
</tbody>
</table>

1/ No definite information as to the exact place of sampling is available. When the nonoutgassed sample in table 3 was applied for it was understood that it was to be a duplicate of the previous sample, that is, that in table 2. Presumably the samples were taken at places close to one another.

2/ The pressure in the system was generally about 3 cm of mercury after pumping off the gas (roughly the vapor pressure of water).

3/ Compositions were determined by the combustion-absorption method with an Orsat apparatus.

4/ Gas removed from the airtight cans containing coal upon arrival in the laboratory.

5/ The coal (in lumps less than 1 3/8 inches) was sealed in screw-cap cans at the working face. Upon receipt several days later (May 16, 1931) the walls of the cans had been forced outward by the excess pressure within. This gas, collected by water displacement, constitutes sample 1 above. The coal was then crushed to pass a 1⁄2-inch mesh screen and immediately placed in a glass flask and the latter sealed to a Toepler pump. The gas in this system (mostly air) was removed with an oil pump and the system sealed off. The real period of pumping began on Sept. 5, 1931 when sample 2 was removed with the Toepler pump.

6/ Some air was accidentally admitted to the system.
TABLE 3. — Gases obtained upon grinding wet Pocahontas coal, no. 4 bed (Consolidated Coal Co. mine no. 261) at room temperature in an evacuated ball mill

<table>
<thead>
<tr>
<th>Initial size of coal</th>
<th>&quot;Outgassed&quot; coal</th>
<th>Coal having no preliminary pumping treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>minus 1/4 inch plus 1/8 inch</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>mini (N.T.P.) per 100 grams of coal</td>
<td>62</td>
<td>2/186</td>
</tr>
<tr>
<td>H₂₃/₄ percent</td>
<td>2.5</td>
<td>---</td>
</tr>
<tr>
<td>CH₄ do.</td>
<td>31.4</td>
<td>57.6</td>
</tr>
<tr>
<td>C₂H₆ (including higher hydrocarbons) do.</td>
<td>1.8</td>
<td>2.8</td>
</tr>
<tr>
<td>N₂ do.</td>
<td>64.5</td>
<td>39.6</td>
</tr>
<tr>
<td>Total volume of evolved per 100 grams of coal cm³</td>
<td>423</td>
<td>112</td>
</tr>
</tbody>
</table>

1/ This sample of coal had been sealed in a glass container which had been evacuated intermittently for 4 months before the ball-mill test. The data in table 2 were obtained with this same coal.

2/ This sample of coal differed from the other in that it exhibited no evidence of pressure in excess of atmospheric upon arrival in the laboratory in friction top cans about Mar. 1, 1932. The test was made about Mar. 12, 1932. Sampling point was in no. 3 heading (counting north to south) on no. 3 south mains, opposite no. 4 right from no. 3 south, in the upper part of the seam (24 inches from top) between splint band and rock binder. The place was wet, had a cover of about 1,300 feet, and was somewhat close to fault area. Information about the sampling place for the outgassed sample as well as the relative rate of face advance for both samples is not sufficiently (table 1, footnote 1) detailed to permit an explanation of their greatly different gas contents. The friction top cans were sealed at the working face and were opened only when it was necessary to remove some coal.

3/ "Probably due to action of acid (from coal) water on ball mill."

4/ Inclusive of gas volume in table 2 for the outgassed sample.
Figure 1.—Sorption of compressed methane by several coals.
Similar ball-mill tests were made of samples of coal from two mines in the Pittsburgh bed; the results are given in tables 4 and 5. Some results reported by Fieldner (78) for coal from the Experimental mine have been converted to a percentage basis and included in table 4 for comparison. The disagreement between the results obtained by the two investigators cannot be explained definitely. Exact agreement is too much to expect, perhaps, in view of the fact that the mine is so near the outcrop. Fieldner's sample may have been exposed to the air a much longer time (either while in place or after mining) than Kembel's. The latter sample should not have been oxidized extensively after mining, as the coal was kept sealed in friction-top cans until used. As actual mining is intermittent in this mine Kembel's sample was obtained when work was in progress.

The very much greater nitrogen content of the coal from the Experimental mine (table 4) compared with that from the Montour mine (table 5) may be due to greater weathering in place. Unfortunately the size range of the coal particles obtained with dry and wet grinding (table 4) was not determined, hence the larger amount of ethane obtained by dry grinding should not be attributed, on the basis of this one experiment, to localized heating. Presumably the latter would not be so pronounced with wet grinding as it might be with dry grinding. However, no one has shown that dry grinding causes any decomposition of the coal with simultaneous formation of gas.

SORPTION OF COMPRESSED GASES BY COALS

While the gas content of coals removed from the mine sometimes may be of interest, it appears that it is the gas content before mining and the ease with which this gas is given up by the coal which have greatest practical importance at present. Due partly to this reason and partly to the fact that the available data on occluded gases in mined coals have so little in common with the gas content of unmined coals no detailed intercomparisons of such data have been attempted.

In reviewing the published data on the sorption of compressed methane by coals one finds that identical units were not used by the several authors. This has necessitated conversion to common units so that the several data may be comparable. The results, corrected in this manner, have been plotted, and the quantities sorbed at arbitrary gage pressures have been read off and tabulated in terms of the volume of gas sorbed in cubic centimeters (corrected to 0° C. and 1 atmosphere or N.T.P.) per 100 grams of coal. The pressures in figure 1 and tables 6 and 7 are expressed in atmospheres gage, and the volumes are those sorbed above 1 atmosphere absolute. It is felt that these quantities more nearly approximate those taking part in gas outbursts or the normal emission of gas in mines. No attempt has been made to correct these results to a common experimental temperature or for variation in composition of the gases used by the several investigators. While the sorption values do not correspond, due to these variations, it is their magnitude and not their absolute values which have primary interest here. In view of the nonexistence of the necessary data any corrections that might be made would be little better than guesses.
TABLE 4. - Amount and composition of gas evolved by Pittsburgh bed coal\(^1\)/ from the U. S. Bureau of Mines Experimental mine, Buceton, Pa., when ground under water in an evacuated ball mill

<table>
<thead>
<tr>
<th>Initial size of coal</th>
<th>Fieldner(^2)/</th>
<th>Kembel(^3)/</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>minus (\frac{3}{8}) inch plus (\frac{1}{4}) inch (by inference)</td>
<td>minus (\frac{3}{8}) inch plus (\frac{1}{4}) inch plus (\frac{1}{8}) inch</td>
</tr>
<tr>
<td>Grinding time - - - - hours</td>
<td>2.</td>
<td>4/2</td>
</tr>
<tr>
<td>Volume of gas evolved(N.T.P.) per 100% of coal - - - - cm(^3)</td>
<td>48.9</td>
<td>31</td>
</tr>
<tr>
<td>C(_2)H(_2) - - - - - percent</td>
<td>17.0</td>
<td>4.0</td>
</tr>
<tr>
<td>H(_2) - - - - - do.</td>
<td>1.3</td>
<td>4.0</td>
</tr>
<tr>
<td>CH(_4) - - - - - do.</td>
<td>13.5</td>
<td>4.4</td>
</tr>
<tr>
<td>C(_2)H(_6) (including higher hydrocarbons) - do.</td>
<td>5.1</td>
<td>1</td>
</tr>
<tr>
<td>N(_2) - - - - - do.</td>
<td>64.4</td>
<td>91.2</td>
</tr>
</tbody>
</table>

\(^1\) This bed outcrops on three sides of the hill under which this sample of coal was obtained, therefore one would not expect to find a great deal of gas. The coal (71) in this mine has suffered alteration by weathering up to a distance of about 50 feet from the outcrop **.**

\(^2\) This coal may have been ground dry rather than wet. Sampling place in the mine is unknown.

\(^3\) Presumably these tests were made upon a sample of coal received about Oct. 27, 1931 from no. 1 room off B butt entry where the cover is about 90 feet thick and the distance to the outcrop about 750 feet. If another coal sample was used its sampling place was in the same part of the mine.

\(^4\) Gas analyzed Jan. 22, 1932.

\(^5\) Gas analyzed Feb. 8, 1932.

\(^6\) Gas analyzed Jan. 15, 1932.

\(^7\) "Probably due to action of acid water on ball mill."
TABLE 5. — Amount and composition of gas evolved by Pittsburgh bed coal from Montour mine no. 10, when ground both dry and wet in an evacuated ball mill

<table>
<thead>
<tr>
<th>Initial size of coal</th>
<th>minus 1/4 inch</th>
<th>minus 1/4 inch minus 1/4 inch</th>
<th>plus 1/8 inch</th>
<th>plus 1/8 inch plus 1/8 inch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grinding time — — — — — — — hours</td>
<td>6(wet)</td>
<td>12(wet)</td>
<td>12(dry)</td>
<td></td>
</tr>
<tr>
<td>Volume of gas evolved (N.T.P.) per 100 g of coal — — — — cm³</td>
<td>2/250</td>
<td>3/238</td>
<td>4/360</td>
<td></td>
</tr>
<tr>
<td>CO₂ — — — — — — — percent</td>
<td></td>
<td></td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>H₂ — — — — — — — do.</td>
<td></td>
<td>1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH₄ — — — — — — — do.</td>
<td>97.8</td>
<td>95.8</td>
<td>85.4</td>
<td></td>
</tr>
<tr>
<td>C₂H₆ (including higher hydrocarbons) — — do.</td>
<td>.3</td>
<td>3.1</td>
<td>11.6</td>
<td></td>
</tr>
<tr>
<td>N₂ — — — — — — do.</td>
<td>1.9</td>
<td></td>
<td>1.9</td>
<td></td>
</tr>
</tbody>
</table>

1/ Sample was taken (received Feb. 5, 1932) from no. 20 face, entry off no. 7 butt, in Montour mine no. 10 of the Pittsburgh Coal Co. The sampling place had a cover of about 325 feet; it was about 20 feet beyond a clay vein and was a foot below the draw slate. Gas was issuing freely from the face.

2/ Gas analyzed Feb. 27, 1932.
4/ Gas analyzed Mar. 11, 1932.
5/ "Probably due to action of acid water on ball mill."
TABLE 6. Sorption of carbon dioxide, \( \text{cm}^3 \) (N.T.P.) per 100 grams of coal

<table>
<thead>
<tr>
<th>Pressure, atmospheres</th>
<th>Briggs(14, 7) 150°C.</th>
<th>Graham (33) 10.8°C.</th>
<th>Leprince Ringuet (56) 13°C.</th>
<th>Ruff (86, 88) 21°C.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moisture 1.23 percent</td>
<td>Moisture 10.3 percent</td>
<td></td>
<td>(1)(^5)</td>
</tr>
<tr>
<td>1</td>
<td>250</td>
<td>500</td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>2</td>
<td>440</td>
<td>860</td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>4</td>
<td>670</td>
<td>1,360</td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>6</td>
<td>820</td>
<td>1,760</td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>8</td>
<td>930</td>
<td>2,120</td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>10</td>
<td>1,030</td>
<td>2,420</td>
<td>1,260</td>
<td>1,450</td>
</tr>
<tr>
<td>15</td>
<td>--</td>
<td>3,060</td>
<td>1,630</td>
<td>--</td>
</tr>
<tr>
<td>20</td>
<td>--</td>
<td>3,640</td>
<td>1,940</td>
<td>1,750</td>
</tr>
<tr>
<td>30</td>
<td>--</td>
<td>4,720</td>
<td>2,440</td>
<td>2,150</td>
</tr>
<tr>
<td>40</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

1/ Dried Pontheury outburst anthracite.
2/ 200-mesh Barnsley soft coal, dried and undried.
3/ Fontanes coal.
4/ (1) Ruben mine, Rüschchen bed, fourth level, borehole borings, considerable gas evolution but as yet no outbursts.
   (2) Ruben mine, Anton bed, fourth level, coal contains considerable carbon dioxide and liable to outbursts (ausbruchgefährlich).
   (3) Wenceslaus mine, third Wilhelm bed, soft (weich), gas evolved was 90% \( \text{CO}_2 \) and liable to outbursts.
   (4) Same as (3) except the coal was hard (fest) and liable to outbursts.
   (5) Wenceslaus mine, fifth Wilhelm bed, hard, gas evolved was 90% \( \text{CO}_2 \) and liable to outbursts.
   (6) Wenceslaus mine, Wenceslaus bed, soft, gas evolved was 10% \( \text{CO}_2 \) and not liable to outbursts.
   (7) Same as (6) except the coal was hard.
   (8) Ludwig-Glück mine, upper Silesia, hard, powdered bright coal (Glanzkohle).
   (9) Same coal as in (10) but in small pieces. No value was given in reference (88).
   (10) Wenceslaus mine, fusain (Fusit) from the different beds.
   (11) Ruben mine, pieces of coal tested were thrown out by an outburst.

5/ The figures in these columns were taken from table 7 of reference (88). The data in the other columns under Ruff were estimated from curves in Ruff's paper (48).
TABLE 7. - Sorption of methane, cm$^3$ (N.T.P.) per 100 grams of coal

<table>
<thead>
<tr>
<th>Pressure atmospheres</th>
<th>Briggs (4, 7) 15$^\circ$ C., dried Pontheny anthracite</th>
<th>Graham (35) 10.8$^\circ$ C., 200-mesh Barnsley soft; moisture</th>
<th>Leprince-Ringuet (56) 16$^\circ$ C.,</th>
<th>Ruff (86) 219 $^\circ$ C.</th>
<th>1/</th>
<th>2/</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Outburst</td>
<td>Normal</td>
<td>Gas purity 1.23 percent</td>
<td>Gas purity 10.3 percent</td>
<td>Gas purity 16$^\circ$ C.,</td>
<td>Gas purity 90 percent or less</td>
</tr>
<tr>
<td>----------------------</td>
<td>----------</td>
<td>--------</td>
<td>------------------------</td>
<td>--------------------------</td>
<td>--------------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>1</td>
<td>130</td>
<td>60</td>
<td>180</td>
<td>70</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>2</td>
<td>220</td>
<td>130</td>
<td>340</td>
<td>140</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>4</td>
<td>360</td>
<td>270</td>
<td>570</td>
<td>260</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>6</td>
<td>440</td>
<td>350</td>
<td>740</td>
<td>360</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>8</td>
<td>470</td>
<td>400</td>
<td>880</td>
<td>460</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>10</td>
<td>500</td>
<td>420</td>
<td>1,020</td>
<td>540</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>15</td>
<td>---</td>
<td>---</td>
<td>1,290</td>
<td>740</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>20</td>
<td>---</td>
<td>---</td>
<td>1,530</td>
<td>920</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>30</td>
<td>---</td>
<td>---</td>
<td>1,980</td>
<td>1,240</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>40</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>690</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>60</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>740</td>
<td>---</td>
</tr>
<tr>
<td>80</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

1/ No temperature was given by Ruff in the original paper. The temperature was 21$^\circ$ for his carbon dioxide experiments, and this temperature has been assumed to apply for methane also, when correcting the volumes to 0$^\circ$ C.

2/ (4a) Gluchilf-Friedenshoffung mine, Ndr. (lower)-Hermsdorf, 18 bed, 7th level, outburst cannel below 1 mm in size.
   (4b) Same as (4a), grain size above 1 mm.
   (5a) Same mine, bed, and level as (4a), crushed in place (?) (Niederstorosz v. Ost), grain size below 1 mm.
   (5b) Same coal as (5a) except the grain size was above 1 mm.
   (6a) Wenceslaus mine, 5 Wilhelm bed, 3 - 2 levels, coal liable to outbursts near the roof (?) (in der Schwe-benden), grain size below 1 mm.
   (6b) Same as (6a), but grain size was above 1 mm.
   (7a) Wenceslaus mine, Wenceslaus seam, grain size below 1 mm.

3/ Sorption at 1 atmosphere absolute was taken as 130 cm$^3$ per 100 g of coal.
Further work on the sorption of compressed methane by coal is being conducted by the author. Although the results obtained so far have been discussed in detail elsewhere (39), they will be summarized herein for convenience. Except in the case indicated, all coals used in these tests were undried to permit determination of the sorptive capacity of the natural coals. Each sample was obtained at a face being actively worked and was immediately sealed in a friction-top can to prevent all but superficial oxidation during the interval between collection and use. Most of these samples were not representative of a vertical section of the whole bed from which they were taken, were obtained through the courtesy of the mine operators, and were simply miscellaneous lumps of coal presumably selected at random by the collector (usually just after the coal had been shot down). The available information concerning the characteristics of these several coals is given in Table 8.

Most of the values for the sorption of compressed methane shown in Table 9 were obtained at 350°C; the isolated values at other temperatures were obtained when the thermostat was not operating and hence may be less satisfactory. The volumes of gas sorbed at 350°C and above 1 atmosphere absolute are plotted in Figure 1, the pressures being in atmospheres gage. These curves indicate a rough correlation between the sorptive capacity and the rank of a coal, the capacity increasing as the rank increases, at least up to the anthracites. While the curves for the semibituminous and the anthracitic coals are in the proper order below 100 atmospheres, too much significance should not be attached to this fact because the differences between them are of the same magnitude as the estimated maximum experimental error, that is, about 100 cm$^3$. The tests with several sizes of Pittsburgh bed coal do not show any definite relationships between sorptive capacity and particle-size distribution. Of course the rate at which the gas is sorbed does vary with this distribution. The single test with the dried coal shows that the capacity increases considerably upon drying, even when the original coal had a low moisture content. If the graphite employed is roughly representative of natural graphites the sorptive capacity of coals must reach a maximum somewhere within the anthracitic range of ranks.

A plot of Graham's (see Table 7) data for the undried Barnsley soft coal is included in Figure 1 for comparison. If an increase of about 100 cm$^3$ in sorptive capacity per 100°C decrease in temperature is assumed for the higher-rank coals on the basis of the present as well as previous work, the Barnsley coal may be seen to be roughly comparable with the Pittsburgh bed coal. If, after correcting for temperature, a correction is made for the greater amount of water in the Barnsley coal the apparent discrepancy is then a little too small, since water is a poorer solvent (28) than coal is a sorbent in this instance.
Table 8.—Screen and chemical analyses\* of the coals used in the sorption tests, in percent.

<table>
<thead>
<tr>
<th>Experiment No.</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7a</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>90-mesh</td>
<td>45-mesh</td>
<td>20-mesh</td>
<td>30-mesh/45-mesh (partly dried)</td>
<td>45-mesh</td>
<td>Pocahontas</td>
<td>Graphite</td>
<td>Pennsylvania</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>anthracite</td>
</tr>
<tr>
<td>Sieve range:</td>
<td>- 20 + 28</td>
<td>- -</td>
<td>- -</td>
<td>13.2</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td></td>
<td>- 28 + 48</td>
<td>- -</td>
<td>- -</td>
<td>28.2</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td></td>
<td>- 48 + 60</td>
<td>- -</td>
<td>- -</td>
<td>5.2</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td></td>
<td>- 45 + 60</td>
<td>- -</td>
<td>- -</td>
<td>12.0</td>
<td>- -</td>
<td>- -</td>
<td>10.0</td>
<td>- -</td>
</tr>
<tr>
<td></td>
<td>- 60 + 80</td>
<td>- -</td>
<td>- -</td>
<td>7.9</td>
<td>(9)</td>
<td>- -</td>
<td>18.3</td>
<td>- -</td>
</tr>
<tr>
<td></td>
<td>- 60 +100</td>
<td>- -</td>
<td>- -</td>
<td>13.9</td>
<td>- -</td>
<td>6.1</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td></td>
<td>- 70 +100</td>
<td>- -</td>
<td>- -</td>
<td>11.0</td>
<td>- -</td>
<td>- -</td>
<td>11.0</td>
<td>- -</td>
</tr>
<tr>
<td></td>
<td>- 90 +150</td>
<td>- -</td>
<td>- -</td>
<td>17.3</td>
<td>- -</td>
<td>3.5</td>
<td>- -</td>
<td>14.7</td>
</tr>
<tr>
<td></td>
<td>-100 +200</td>
<td>- -</td>
<td>- -</td>
<td>10.1</td>
<td>- -</td>
<td>4.2</td>
<td>8.5</td>
<td>- -</td>
</tr>
<tr>
<td></td>
<td>-200</td>
<td>- -</td>
<td>- -</td>
<td>78.3</td>
<td>24.3</td>
<td>10.7</td>
<td>40.4</td>
<td>21.7</td>
</tr>
<tr>
<td>Proximate analysis (as-received basis):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>- -</td>
<td>1.3</td>
<td>1.2</td>
<td>0.4</td>
<td>0.4</td>
<td>0.04</td>
<td>1.9</td>
<td>26.2</td>
</tr>
<tr>
<td>Volatile matter</td>
<td>- -</td>
<td>79.6</td>
<td>40.0</td>
<td>41.7</td>
<td>15.4</td>
<td>- -</td>
<td>2.5</td>
<td>27.5</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>- -</td>
<td>56.4</td>
<td>55.7</td>
<td>54.3</td>
<td>81.3</td>
<td>- -</td>
<td>91.2</td>
<td>42.4</td>
</tr>
<tr>
<td>Ash</td>
<td>- -</td>
<td>2.7</td>
<td>3.1</td>
<td>3.6</td>
<td>2.9</td>
<td>5.57</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td>- -</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>- -</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Air-dry loss</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>Ultimate analysis (as-received basis):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>(10)</td>
<td>5.7</td>
<td>5.7</td>
<td>5.8</td>
<td>4.4</td>
<td>- -</td>
<td>2.2</td>
<td>6.5</td>
</tr>
<tr>
<td>Carbon</td>
<td>- -</td>
<td>80.9</td>
<td>80.6</td>
<td>80.6</td>
<td>88.7</td>
<td>- -</td>
<td>89.8</td>
<td>53.6</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>- -</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.3</td>
<td>- -</td>
<td>1.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Oxygen</td>
<td>- -</td>
<td>7.8</td>
<td>7.7</td>
<td>7.1</td>
<td>2.2</td>
<td>- -</td>
<td>2.3</td>
<td>34.4</td>
</tr>
<tr>
<td>Sulphur</td>
<td>- -</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
<td>5</td>
<td>- -</td>
<td>4.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Ash</td>
<td>- -</td>
<td>0.27</td>
<td>0.31</td>
<td>0.36</td>
<td>2.9</td>
<td>- -</td>
<td>100.0</td>
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<tr>
<td>Total</td>
<td>- -</td>
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<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>- -</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

* See next page for footnotes.
<table>
<thead>
<tr>
<th>Experiment No.</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7a</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pittsburgh bed (2)</td>
<td>(bituminous coal)</td>
<td>Pocahontas no. 4 bed (3)</td>
<td>(semibituminous)</td>
<td>Graphite (4)</td>
<td>Pennsylvania anthracite</td>
<td>North Colorado</td>
<td>Graham's Barnett (35)</td>
</tr>
<tr>
<td>Maximum screen size</td>
<td>90-mesh</td>
<td>45-mesh</td>
<td>20-mesh</td>
<td>(partly dried)</td>
<td>45-mesh</td>
<td>45-mesh</td>
<td>45-mesh</td>
<td>200-mesh</td>
</tr>
<tr>
<td>Calorific value, calories</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7.79%</td>
<td>5.13%</td>
</tr>
<tr>
<td>Density, (g/cm^3)</td>
<td>1.301</td>
<td>1.316</td>
<td>1.316</td>
<td>1.301</td>
<td>1.416</td>
<td>1.64%</td>
<td>1.64%</td>
<td>1.43%</td>
</tr>
<tr>
<td>Date sample was collected in mine</td>
<td>May 2, 1931</td>
<td>May 2, 1931</td>
<td>May 2, 1931</td>
<td>May 2, 1931</td>
<td>About July 9, 1932</td>
<td>About Sept. 15, 1932</td>
<td>Nov. 28, 1932</td>
<td></td>
</tr>
</tbody>
</table>

1/ Analyses made by the Bureau coal analysis laboratory, H. M. Cooper in charge.
2/ Sample taken in the Bureau Experimental mine (probably in room no. 2 off S. left butt entry, or in this vicinity) at a point 6 inches from top of the 61-inch bed. Sample had 50 feet of cover and was not wet or gassy; distance to crop line is about 530 feet. Courtesy of H. C. Howarth and H. P. Greenwald. Experimental mine near Bruceton, Pa.
3/ Sample taken in Consolidated Coal Co. mine 261 in no. 3 heading (counting north to south) on no. 3 south mains opposite no. 4 right from no. 3 south, in upper part of the bed (24 inches from top) between splint band and rock binder. Place was wet, had a cover of 1,300 feet, and was somewhat close to a fault area. This is a very gassy mine. Courtesy of H. H. Forester. Mine 261 near Carena, McDowell Co., W. Va.
4/ Dixon's Ticonderoga no. 2 powdered flake graphite (for lubricating purposes). Sample used as it came from the can.
5/ Coal from Maple Hill Colliery of the Philadelphia & Reading Coal & Iron Co. Mammoth bottom split, no. 22 rock hole off West Skidmore no. 29 tunnel. Vein 31 feet thick, pitching 28°; 700 to 750 feet of cover. Drainage excellent, coal dry, not a gassy place. Sample from bottom bench 6 foot solid pillar. Courtesy of Dr. R. C. Johnson. Mine near Shenandoah, Schuylkill Co., Pa.
6/ Face sample from Grant mine, Frederick, Colo. Cretaceous bed of lower Laramie formation, flat lying. Sampled by standard method from fresh, dry coal in 51 north butt entry 100 feet off 33 west. Bed was 6 feet 5 inches thick, had a soft shale roof, 1 1/2 inch roof coal, hard smooth floor, and a cover of 165 feet. Courtesy of Annsden and Bird.
7/ After being used in experiment 2 this sample was kept in an evacuated desiccator containing sulphuric acid for 3 months before being used in experiment 5.
8/ This coal was fairly fine to start with (mostly 1/2 inch or less). It was passed quickly through the Bureau's jaw crusher and twice through the rolls, the total air exposure being a matter of several minutes. The rolls packed some of the coal into flakes, hence a screen analysis probably would be a poor indication of effective size.
9/ Same sample as that in experiment 2.
10/ This coal was used again in experiment 5, after partial drying, then analyzed.
11/ The "true" specific gravities reported by the coal analysis laboratory are said to be referred to water at 20° C.; hence, they have been corrected to water at its greatest density.
TABLE 9. - Sorption of compressed methane per 100 grams of sorbent

<table>
<thead>
<tr>
<th>Experiment no. and coal rank</th>
<th>Temperature, °C</th>
<th>Volume sorbed (N.T.P.), cm³</th>
<th>Equilibrium pressure, atmosphere absolute</th>
<th>Volume sorbed at 35°C. and 1 atmosphere absolute (N.T.P.), cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2) Bituminous</td>
<td>35</td>
<td>1,130</td>
<td>90.48</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>1,070</td>
<td>67.22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>900</td>
<td>33.93</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>770</td>
<td>41.75</td>
<td></td>
</tr>
<tr>
<td>(3) Bituminous</td>
<td>35</td>
<td>1,130</td>
<td>106.84</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>1,060</td>
<td>64.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>900</td>
<td>35.60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>660</td>
<td>15.22</td>
<td></td>
</tr>
<tr>
<td>(4) Bituminous</td>
<td>35</td>
<td>1,160</td>
<td>107.43</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>1,070</td>
<td>73.65</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>860</td>
<td>35.82</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>610</td>
<td>15.85</td>
<td></td>
</tr>
<tr>
<td>(5) Bituminous</td>
<td>35</td>
<td>1,420</td>
<td>91.78</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25.7</td>
<td>1,480</td>
<td>87.54</td>
<td></td>
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<tr>
<td>(6) Semibituminous</td>
<td>35</td>
<td>2,290</td>
<td>97.21</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>2,050</td>
<td>56.77</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>1,780</td>
<td>33.54</td>
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<td>35</td>
<td>1,380</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>27.7</td>
<td>2,370</td>
<td>93.52</td>
<td></td>
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<tr>
<td></td>
<td>25.5</td>
<td>1,860</td>
<td>31.86</td>
<td></td>
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<tr>
<td></td>
<td>24.5</td>
<td>1,490</td>
<td>14.42</td>
<td></td>
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<tr>
<td>(7a) Graphite</td>
<td>35</td>
<td>100</td>
<td>92.92</td>
<td>20</td>
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<tr>
<td></td>
<td>35</td>
<td>100</td>
<td>63.63</td>
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</tr>
<tr>
<td></td>
<td>35</td>
<td>80</td>
<td>29.57</td>
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</tr>
<tr>
<td></td>
<td>35</td>
<td>70</td>
<td>12.65</td>
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</tr>
<tr>
<td>(8) Anthracite</td>
<td>35</td>
<td>2,290</td>
<td>93.59</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>2,200</td>
<td>66.22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>1/ 1,770</td>
<td>31.70</td>
<td></td>
</tr>
<tr>
<td>(9) Subbituminous</td>
<td>35</td>
<td>440</td>
<td>111.62</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>360</td>
<td>69.69</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>240</td>
<td>36.58</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>150</td>
<td>15.23</td>
<td></td>
</tr>
</tbody>
</table>

1/ This value may be a little too small due to nonequilibrium.
Incidental to determination of the equilibrium sorption values it was possible to obtain some information on the rate at which the gas is picked up by several coals when the compressed methane was admitted thereto. In all instances the gas was taken up quite rapidly at first and then more slowly, as shown in figure 2. The slow part of the sorption undoubtedly is determined by the rate at which the methane could penetrate the innermost parts of the solid. These curves do not correspond exactly to the same final equilibrium pressure; 100 percent completion of sorption occurred at the highest experimental pressures shown in table 9. Because of nonequilibrium in temperature and pressure the curves in figure 2 have no particular significance in the 20-minute interval just after the admission of methane.

It is possible that the sorption results reported by Briggs are too low, due to nonattainment of equilibrium (33). The same might be true of some of those reported by Leprince-Ringuet, although too little experimental detail was given on which to form an opinion. Graham’s results doubtless do correspond to equilibrium; the author has found that 90-mesh coal (Graham employed 200-mesh) did reach approximate equilibrium at pressures considerably in excess of those used by Graham, within the time interval (16 hours) allowed by the latter investigator. At least some of Ruff's results, particularly for those experiments in which the larger coal sizes were employed, are admittedly (87) too low. For the smaller sizes of coal the relative magnitudes of Ruff's values for both methane and carbon dioxide possibly are about the same as if equilibrium had been reached.

While Briggs' results might indicate a somewhat greater sorptive capacity for the outburst coal than for the nonoutburst coal from the same seam; Ruff's results do not support this view. Furthermore, the results reported by the author certainly do not indicate that the sorption is greater the finer the coal. Ruff has reached the same conclusion on the basis of his results. Perhaps deviations might be observable with still finer coal, but it is unlikely that the increase would be great enough to have practical significance.

For identical temperatures and pressures the sorption of carbon dioxide exceeds that of methane, usually by a wide margin. The figures for the carbon dioxide sorption probably involve greater absolute errors in volume than those for methane for Ruff's nonequilibrium results if the same time interval was allowed with both carbon dioxide and methane.

Because of the rough correspondence of sorptive capacity to rank one would not expect the sorption values in tables 5 and 6 to be in exact agreement for all the coals even if all the values were for true equilibrium. Undoubtedly there were intrinsic sources of error in the various experimental methods employed, but due to the absence of descriptive detail an estimation of such errors is impossible. For Ruff's more finely divided and soft coals, which may not have reached equilibrium, the values cited in tables 6 and 7 are believed to be at least 75 percent the true equilibrium value.
Figure 2.—Variation of extent to which sorption is complete with time.
FACTORs INFLUENCING EMISSION OF GAS IN COAL MINES

There is no doubt but what some sections of a mine in a given coal bed often evolve more methane (13, p. 17; 47), or CO₂ perhaps, than do others. Likewise mines in the same bed, even when they are near one another, do not necessarily evolve comparable quantities of gas (39), although if one is gassy the other also probably will be more or less gassy. While these observations have been interpreted as implying that the gas content of the coal in place varies within relatively short distances, the question is not answered so simply. It is almost impossible to make corrections for the gas entering the various sections of the mine via blowers and variations in the gas seepage from adjacent strata (36). The usual method of surveying the quantities of gas in the ventilating air current at various places within a mine therefore is incapable of indicating the actual quantities of gas contained in, or evolved by, the coal itself.

Theoretically, the two possible components of the gas flow, that is, the flow through the coal bed and the flow through adjacent strata, must be considered as separate entities. Probably the flow in these two channels will be so dissimilar that any attempt to study their composite character would be hopelessly complex. To what extent the separate flows are susceptible to experimental study is a question yet to be investigated. Unless layers of some very impervious material lie between the coal bed and the other strata through which the gas flows the pressure gradient in both must be the same, irrespective of the subdivision of the total gas flow. Hence, pressure measurements in the respective strata could not be used to differentiate between the separate flows. If one could locate a number of coal beds of given character but different adjacent strata as well as a number of coal beds of different character but identical adjacent strata, some useful generalizations might be drawn therefrom on the basis of the respective pressure gradients and composite flow rates. It would appear to be impossible to separate the individual flows in any other way. The problem is simplified only if one or the other of these flows is negligible with respect to the other.

There is no existing excuse for such surveys of gas flow, unless it appears possible to predict therefrom the gas flow from proposed mines or gas wells in virgin coal beds. For the latter the initial flow can be found experimentally, without any knowledge of the gas-bearing bed and strata, since a few wells drilled to determine pressures will always be available for this purpose. However, it will be necessary to know something about the component gas flows (and possibly the gas content of the coal also, neglecting the small amount of gas sorbed by other materials) if one wishes to predict the possible gas flow at some future date. A priori it would appear that the flow through coal apparently having the same characteristics would vary less (on a percentage basis) from place to place than that through adjacent strata.

So far there is no evidence that a borehole can be drilled from the coal face through an appreciable fraction of the effective depth of the drainage belt, so only a small part of the pressure gradient can be ascertained in this
manner. The remaining part must be determined by drilling a number of holes from the surface to the coal bed at strategic points and measuring the gas pressure therein. If the gradient could thus be determined satisfactorily the over-all permeability could be estimated on the basis of this gradient and the known rate of gas flow into a mine. It is conceivable that if enough beds and mines were so examined a range of permeabilities would be found which, in combination with gas pressures determined directly in a virgin coal bed, could be used to estimate within limits the flow to be expected at potential drainage points in similar but virgin coal beds. However, local conditions might so outweigh the generalities as to minimize the value of such predictions. Of course this is not proved, but the rather great variation in gas emission from adjacent mines certainly offers qualitative support.

The coal bed often comprises layers which differ considerably in characteristics and presumably also in permeabilities, to say nothing about the cracks in the coal and the variations in the roof and floor. When a good part of the total gas flow occurs in adjacent strata or through extensive interlocking cracks in the coal, obviously it is impossible to study in the laboratory all the factors influencing the flow. This point cannot be stressed too much. Some laboratory studies have been made, but the coal samples certainly were not representative of the entire coal face. In spite of the probable experimental difficulties it appears worth while to devote a little thought to the situation, even though only a very ideal case can be so treated.

Consider an ideal case in which the undisturbed coal (perhaps also adjacent strata) for some as yet indefinite distance back of the coal face serves simply as an obstruction to the free outflow of gas from an inexhaustible gas reservoir further back. The pressure gradient in this "plug" would then approach a steady state if the over-all permeability of the coal bed does not change with time and if the depth of the drainage belt remains constant as mining progresses. Here, the gas content of the coal at any point in the drainage belt has no consequence with respect to the rate of gas emission after the gradient is once established. In all probability, however, the pressure gradient will change with time in a great many cases. If then, the permeability and gas content of the small blocks of coal between the

---

There may be a connection between these factors in that the permeability of those portions of the coal which do not contain passages large enough for viscous gas flow and the capacity of the coal for sorbed gas may be interrelated - suggested by H. H. Storch. This possibility rests upon a detailed picture (the validity of which has not been adequately tested) for both the mechanism by which the gas passes through the "solid" coal and the mechanism effecting the concentration of the gas. Such a connection can have no practical significance unless there is a fixed relationship for all coals, respectively, between this permeability and the amount of gas sorbed at some fixed pressure. Otherwise, the two quantities would have to be determined for each coal.
natural cleavage planes and partings in the coal bed is such as to render the volume of gas evolved by all these blocks within the drainage belt an appreciable fraction of the total gas emission, the rate at which the pressure gradient will change, hence the rate at which the rate of gas evolution will change must depend upon the gas content of the coal. However, the instantaneous rate of gas emission\(^{23}\) at any drainage point is solely a function of the pressure gradient within and the effective permeability of this "plug" or "drainage belt." Presumably these two quantities would seldom be the same for any two beds or for widely different parts of the same bed. Theoretically, then, it is possible to start with two identical mines, having equivalent pressure gradients back of the face and instantaneous rates of gas emission, in beds of the same over-all permeability and later find that the instantaneous rates differ due to different original gas contents of the respective coals. Moreover, if the mining activity causes changes in the pressure gradient the instantaneous rate of gas emission will vary accordingly; the gas content and permeability of the uncreviced blocks of coal then determine in part the rate at which these fluctuations take place.

It is well known that most mines evolve greater quantities of gas when work is in progress than when they are idle, indicating that the gas content of the coal affected by the advancing workings serves as a source of a good part of the total gas emission\(^{24}\) and/or that the drainage belt is much thinner than one ordinarily would suppose it to be. As yet the effect of mining operations upon the thickness of the drainage belt is unknown. If the belt is rather thin, as a great many writers infer, mining operations undoubtedly alter its thickness appreciably. This view seems a little illogical if a large fraction of the gas does not come from the coal in the vicinity of the face. In any case the original gas content and permeability of the uncreviced and approximately homogeneous (macroscopically at least) blocks of coal have no influence upon the instantaneous rate of gas emission from the coal face. Since these factors bear some relationship to emission of gas by the broken coal a brief discussion of this permeability\(^{25}\) seems desirable. Graham alone

\(^{23}\) This picture of the system is largely the result of conversations with S. F. Burke of the University of West Virginia and L. S. Kassel of the Bureau of Mines. Burke probably will publish a more detailed analysis elsewhere.

\(^{24}\) This emission is based upon the gas content of the mine air; the foregoing discussion is not concerned with the gas evolved by the broken coal, even though the latter may represent a good fraction of the total.

\(^{25}\) This permeability will vary supposedly from block to block and has no relationship to the over-all permeability of the coal bed.
seems to have attempted a direct measurement (37, 38) of this permeability\(^\text{26}\). The experimental difficulties were rather great, particularly for the soft coals, and the values obtained are only valid for lumps quite similar in all respects to those tested. The results indicate that some coals are extremely impermeable, so impermeable, in fact, that it is difficult to see how they could give off any gas without a very extensive system of interlocking cracks and relatively permeable parting planes in the coal.

Ruff and his coworkers\(^\text{28}\) use an indirect method which with refinement might yield some information about the relative permeability of different samples of these little coal blocks, provided certain intrinsic assumptions can be justified. In these experiments the rate of evolution of gas from coal which had been in the presence of the compressed gas for more or less extended periods, was studied rather incompletely after the gas pressure was released. For experiments of this kind the coal must be crushed to a rather fine power\(^\text{27}\) in order to impregnate the coal particles uniformly with the gas in a reasonable time. The nonuniformity in particle size may be quite a hindrance when correlation of the rates of gas emission is attempted after the common initial gas pressure on the samples is reduced to the chosen value (usually atmospheric pressure) of the several samples. If the samples could be crushed so that the particle-size distribution was approximately the same for all the rates of gas evolution presumably would indicate the relative permeabilities of the solid blocks of coal from which the samples were taken. This assumes that the amount of gas sorbed by the various coals is either approximately the same or at least varies much less than their permeability. If not, the rates of emission do not determine the permeabilities uniquely. Thus, consider a homogeneous sphere of solid "coal" impregnated with gas at a known pressure. Knowing its permeability, the functional relationship between the amount of sorbed gas per unit weight of solid and the gas pressure, and the pressure difference at zero time (moment of pressure release), one could estimate the rate of evolution as well as the total evolution at any time thereafter.

\(^{26}\) In the International Critical Tables (vol. 5, p. 76) the permeability of a solid to a gas is defined as "the quantity K in the equation

\[
\frac{dm}{dt} = -K \frac{A_P}{2} \frac{dZ}{dx dy},
\]

where \(dm\) is the mass of gas which passes in the direction of \(Z\) and in the time \(dt\) through a diaphragm of the solid area \(dx dy\) and thickness \(dZ\), the difference in pressure on the two sides of the diaphragm (excess on positive side) being \(dP\); the minus sign indicates that the flow is in the direction of decreasing pressure. \(\rho\) is the density of the gas at \(0^\circ\) C. and pressure = \(\Delta n\); \(dm\) = volume of \(dm\) at \(0^\circ\) C. and \(\Delta n\).

The unit for \(P\) is 1 atmosphere and that for \(K\) is cm\(^2\)/atmosphere-second when the lengths are measured in centimeters and the time in seconds. Graham's units differ somewhat from these but the general form of the equation is the same.

The above form of equation is not applicable to diaphragms containing cracks large enough for viscous gas flow or in general to inhomogeneous materials.

\(^{27}\) The author has found that 45-mesh (or smaller) coal will permit the attainment of equilibrium with compressed methane within a satisfactory interval of time, say 2 or 3 days.
The equivalent of size uniformity might be attained by proper screening, the rates of gas evolution for the several size ranges being corrected to give the relative permeabilities of the coals tested. If any segregation of the physical components of the coals occurred during screening still another correction would be necessary. Whether the crushing alters (51) the physical structure of the individual particles is now known. If it does, the apparent size (as determined by screens) may not be a very good measure of the effective size of the particles. It would seem necessary, therefore, to approach this method of studying the relative permeability of coals with considerable caution.

It has been reported that coal from a very gassy bed often does not evolve gas for as long a time after mining as does coal from another source considered less gassy (18). However, the degree of "gassiness" of a given coal cannot be taken as an indication of its original gas content or its permeability. Thus Wood's (59) results do not show a direct correspondence between the maximum gas pressure (and hence gas content approximately) registered by a given borehole and the rate of gas evolution per unit area within the borehole. If one knew that two samples of solid coal of the same rank contained comparable amounts of gas initially and later found that one sample gave up its gas several times faster than the other, he would be justified in concluding that the first sample was the more permeable. It is unlikely that the initial pressures in equilibrium with these two samples would differ greatly.

It is well known that the finer the particles the greater the rate of gas evolution for a given coal with a given gas content. Kemel (48) has found that upon grinding Pittsburgh-seam coal in an evacuated ball mill for 4 hours (the resulting particle-size distribution was not determined) about 350 times as much gas was liberated as was evolved in the same period by 0.5-inch lumps of the same coal under approximately the same pressure. Furthermore, experiments by the Montlucon Testing Station, France, have shown (66) that upon rapid decrease of the gas pressure from 50 atmospheres to 1 atmosphere the 200-mesh coal released three fourths of its gas during the same interval required by the coarse coal (20 to 30 mm) to liberate one fourteenth of its gas. Just how the total gas was determined for either size of coal is not known. Assuming that Kemel's coal was about 200-mesh/ after grinding, there seems to be a rather large discrepancy between the two findings. However, neither the initial pressures nor perhaps the coals themselves were comparable.

At present very little trustworthy information is available concerning the pressure gradients behind the coal faces. Many attempts have been made, most of which are unsatisfactory in some respect, to measure the pressure of gas in the far end of boreholes driven into the coal bed from the coal face.

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The maximum distance investigated so far is about 40 feet. Such distances presumably are only a small fraction of the pressure-gradient range (that range over which the pressure decreases because of gas flowing into an artificial drainage point in the bed such as a mine). Many writers have implied that this range is not very extensive; this may be true in some limiting cases.

Instances have been reported in which the gas pressure near the face was great enough to aid (13, pp. 16 and 22; 64; 78, p. 345; 80; 97; 98) in winning the coal when hand labor was employed, but no information seems to be available as to the amount of this pressure. In general very little gas pressure is ever evident in shallow boreholes (20), indicating either that the coal near the face has lost most of its gas or else that the holes were not gastight.

By the use of deep boreholes driven in from the coal face, Wood and later workers have measured rather high gas pressures (18, 78, 99) in coal (Wood records pressures up to 460 and Cornet up to 670 pounds per square inch) but in general comparatively low pressures have been reported (13, p. 28; 20, p. 60; 78, p. 343; 97, p. 125). Rice (74, p. 115) cites pressures of 500 to 600 pounds per square inch in boreholes sunk to the coal bed from the surface. Rather than assume that the low pressures represent equilibrium pressures in the virgin coal, it seems more logical, especially for those recorded in very gassy mines, to attribute them to leaks either around the borehole walls or through fissures that are believed to extend quite far into the coal bed. Graham and others have reported (9; 18: 32; 49; 74, p. 115) that this "drainage belt" extends in some seams approximately 30 feet (possibly more) from the coal face. Such tests have not been extensive enough to permit any generalizations as to the depth of the "drainage belt." If the interconnecting cracks exist in the entire virgin-coal bed, or if adjacent strata permit some gas flow, the depth will be much greater. It has been assumed in the foregoing discussion that such is the case.

Conversely, some have postulated that most of the gas evolved in mines came from coal in the immediate vicinity of the face. In this case the cracks seen in any coal face are believed to open up as mining progresses. Such cracks or fissures would be self-perpetuating provided Briggs' (6; 13, p. 326) idea that the cracks are due to shrinkage of the coal as the gas escapes has any foundation in fact. This idea was based on the fact that degassed charcoal expands (2, 61) several tenths of a percent when it adsorbs gas. It has since been shown that coal likewise expands when it sorbs gases (3, 53). It is quite probable, then, that coal will shrink as the gas escapes.

29/ Burke (work cited) has recently employed boreholes much longer than any of these. The details are to appear elsewhere.
30/ Rice suggested (78, p. 340) some years ago that the coal airrank upon losing its gas, although he did not attribute the cracks thereto.
Rice objects to this theory on the ground that the coal will flow under pressure and hence fill up any cracks that may form. To quote him in part:

I think that there is not the slightest evidence that this (cracks due to shrinkage) is the case. You might as well attribute the joint planes in sandstones or limestones to such a cause. It seems to me that if the coal does shrink in volume, and I believe it does with the emission of gas, that under normal conditions it would be in a vertical direction. This is because there is a heavy vertical loading*** and many vertical openings - either natural or artificial - would be closed by the flowage of the coal *** as shown abundantly by mining experience.

It is to be noted that other sorbents in general swell or contract in all directions although not to the same extent, perhaps (2, 81).

In view of the foregoing discussion it may be seen that the permeabilities of coals and coal beds are at present uncertain. The evolution of gas in some mines has been shown by Budge (9) to be connected so intimately with the characteristics of the strata above and below the bed and the method of mining that the effect of the character of the coal may be more or less obscured. Thus, if it is assumed that the coal in two different beds is identical, it is possible that mines in the two beds will exhibit different gas evolutions due to different roof and floor characteristics. On the other hand, in the same or adjacent mines it may not always seem logical to ascribe the known variations in gas evolution, from place to place or mine to mine, to the variations in the strata above and below the bed. In such cases the variation in gas emission must be attributed to different rates of flow through the coal and adjacent strata; then one might infer one or more of these conditions in the virgin bed under consideration:

1. The gas pressure varies from one locality to another in the virgin bed, hence the quantity of gas sorbed per unit weight of coal might vary accordingly.

2. The physical and chemical properties of the coal, such as friability, permeability to the gas, and composition, vary from place to place.

3. The coal may be capable of sorbing more gas, at a given pressure, in one place than in another.

The first condition is believed to be unlikely (5; 74, p. 115). Probably the gas pressure in the virgin bed is virtually the same throughout extensive areas except for gradations toward outcrops or other drainage points. This assumes, of course, that no excess pressure has been built up in places due to extraneous gas leaking into or by the unequal generation of gas within the seam at a greater rate than can be accommodated by the migration of the gas to areas having a lower gas pressure. If the view is acceptable that the same gas has been confined within the coal bed for an appreciable fraction of the age of the coal, then the over-all permeability would be small indeed if pres-
sure equalization over large areas in the virgin bed has not been effected. Furthermore, it is not believed that localized pressure increases, due to geologic movements, would have remained undissipated during past ages as some authors have suggested in their discussions of outbursts. As Briggs has stated (9), it is very nearly a contradiction in terms to say that a good sorbent is very impermeable. The assumption of great pressure increases in confined areas would be difficult to support even at the time of the movement, unless the coal was heated considerably thereby. This does not appear to have been the case generally. It seems more logical to assume that the high pressure in the outburst cluster is the result of poorer effective drainage therefrom than from the "normal" part of the bed just before the outburst.

The second condition perhaps is true (91), but it does not define the quantity or pressure of the gas in the virgin bed. It explains the experimental facts in that the gas could escape more readily from coal having the appropriate characteristics (assuming nonvariable roof and floor characteristics), hence giving the impression that the coal in question contained more gas originally. In the exceptional coal-bearing regions where instantaneous gas outbursts occur the more friable coal sometimes seems to be more liable (81, 82) to them than the less friable coal. Generally, some peculiar localized geologic movement is indicated in such areas, as elsewhere the friable coal is known to give off its gas very readily, according to Rice. However, since the physical and chemical properties may vary from place to place in the seam, it is quite possible that other properties will also vary; therefore, condition (3) must be considered.

Existing data indicate that no great differences in sorptive capacity are to be found in coals of the same rank regardless of their origin; therefore, coal from various places in the same bed should not exhibit wide differences. Wilson (96), on the basis of the report of the Prussian Committee investigating carbon dioxide outbursts, has expressed the opinion that "in the cluster carbon dioxide is in no larger volume nor under a higher pressure than in the uncrushed coal, the sole difference being that the coal is of a different structure and therefore is able to give off gas rapidly." The same idea has been stated by others. Some have claimed (7), particularly with reference to outbursts, that some portions of a bed were "activated"—that is, the coal within such areas held more gas, other factors being the same, than coal in other parts of the bed. The absence of adequate support for this view has been discussed.

From a practical standpoint there can be little doubt that the gas content of a bed varies considerably within those areas near enough to outcrops, mines, and faults that the gas can drain off more or less readily. It is believed that these variations are dependent more upon the ease with which the gas has been able to seep into and out of the coal bed within these drainage areas than upon variations in sorption capacity. Whenever a mine is started in a bed the coal, in the immediate vicinity at least, can no longer be considered as virgin so far as its gas content is concerned, provided the coal and/or the adjacent rock has a reasonable permeability. If the roof and floor characteristics did not influence this pressure gradient (which is unlikely), then the distance over which it extends would depend only upon the characteristics of the coal within the same range.
INSTANTANEOUS GAS OUTBURSTS

Often these phenomena have been designated rather too loosely by other terms (20, 43, 43, 77). More recently other terms, such as "outbursts", "instantaneous outbursts", and "instantaneous outbursts of gas" (German, Gasausbrüchen; French, dégagements instantanés de gaz), have been used in a restricted sense (75, p. 77; 80, p. 304), that is, where more or less coal and relatively great or very great quantities of gas were released suddenly into the mine workings with little or no warning (17, 22, 93, 97, 98). It is to be emphasized that such phenomena are the exception rather than the rule. As Rice has pointed out, the world contains perhaps 30,000 or 40,000 workings in coal beds large enough to be called mines, while the number which occasionally might be subject to outbursts probably does not exceed a few hundred. Although there are mines in the United States which are eminently gassy it is not believed that any of them have ever had an emission of gas and coal which could unreservedly be called an outburst (76, p. 76). One cannot be sure, however, that future operations in the deeper beds will be immune.

Fortunately, most gassy mines are not afflicted with the outburst danger (18, 39, 90, 97); the nongassy mines are apparently immune to true outbursts. The outbursts generally are rather infrequent, even where they do occur. Some of Kindermann's statistics (49) concerning a few German mines indicate that no definite relationship exists between the frequency of outbursts and the violence thereof. Furthermore, consideration of the available information indicates that no universal relation (13; 47; 75; 82; 90; 97, p. 98) exists between any of the following: The measured gas pressure in boreholes, the quantity of gas evolved, the depth of the bed, and the probability of outbursts. In some coal beds there is said to be partial cessation (4, p. 124) of the normal gas flow just before an outburst. This fact may be related to the observation in some localities that the coal becomes more "dense", "hard", and "compact" as one of the potential outbursts clusters is approached in mining operations. Sin (90) has quoted a little proverb of the French miners which indicates the importance they attach to this observation.

Unless the clusters do correspond to spots in the virgin bed where the gas pressure has remained in excess of that in surrounding parts of the bed through the ages, the excess pressure at the time of the outburst obviously must be the result of poorer effective gas drainage of the area just before the outburst. Kindermann and Tolksdorf (49) have remarked that where the gas-free zone extends a considerable distance from the coal wall the outburst danger is not great.

Wilson and Henderson (98) have reported a case in which outbursts were as liable to occur in coal faces that had been exposed for 2 years as in the virgin coal, provided work was recommenced upon them. Roblings (82) has mentioned a similar case in which considerable gas was quite evident soon after work was restarted upon a face that had been exposed for a considerable time. In such cases there seem to be only two possible explanations; either the gas that drained from the coal back of the face was replaced by inflowing
gas at approximately the same rate (that is, the pressure gradient behind the face remained approximately the same for a certain time after the face in question was exposed), or the gas did not drain off very rapidly. The latter is the usual explanation and assumes that the coal in question was virtually impermeable to the gas.

The depth of the bed has no definite and general relation to outburst occurrence (47); a few instances have been reported in which outbursts occurred in the upper or middle but not in the lower beds (42, 51). For mines in which outbursts occur only in the lower beds, the thickness of the cover probably is just a contributing factor and not the real cause (in that the gas may not escape as readily from the deeper beds either during or before mining).'

There seems to be a rather general opinion that the lower beds are the more gassy. As an exception to this Judge (9) has shown that when some of the upper beds in South Wales were first worked the lower beds later proved to be less gassy. It has been reported (18) also that the deeper the bed the higher are borehole pressures. In any case the relative amount of gas evolved by two beds is no absolute indication of the relative pressures or gas quantities therein. Furthermore, it appears that the occurrence or non-occurrence of outbursts does not necessarily indicate the relative gas pressures in the beds of a coal field affected by these occurrences.

Kindermann and Tollendorf (49) have attempted to relate carbon dioxide outbursts to the percentage of this gas found in boreholes. Their method seems incapable of furnishing more than qualitative information. It has not been tested thoroughly enough to show whether or not similar tests in other coal fields are warranted.

The general idea of the "cluster" or "nest" has existed in the literature for some time (4, 78), but the terminology is more recent. The cluster theory has gained support but still lacks experimental verification. Often, a good part of the coal thrown out (22, 90) is said to be fine (sometimes almost a powder) and friable, although it may be hard (17, 82); in some cases it appears to be dry (4, 7, 98) and sometimes slickensided (4, 98). Rare instances have been reported (4, 7, 19, 81) in which the drilling tool suddenly entered soft coal, "then dust and gas—and sometimes the drill—have been ejected from the hole." These observations have been taken often as definite evidence that the coal in the cluster had been crushed extensively and perhaps altered by lateral strata movements which have affected the bed in that locality. It has been suggested that the coal within the cluster may have been as compact as normal coal, the only difference being that the natural structure has been disrupted leaving a mass of coal with diminished coherence.

Apparently faults are very often, but not always, evident near areas from which outbursts occur. It has not been shown definitely that the violence of the outburst is greater when it occurs near a fault (physical discontinuity in the strata due to relative movement of sections thereof), but at least some of the most violent occurrences in the past were so situated. If there is such a tendency then there are two possible explanations:
(1) The faulting movement generally crushed the coal more effectively in spots (such as are assumed in clusters) than did whole roof-versus-floor movements, and/or (2) the fault planes must have contained open spaces in which appreciable quantities of gas could be stored in the strata adjacent to the coal bed.

Rice has pointed out that the term "fault" might designate more than one type of movement (74, p. 113) and suggested that those movements evidenced by a shearing of the coal bed seldom produce much crushed coal. Apparently such a fault was near one of the most violent outbursts that has yet occurred (40).

In most strata containing coal measures that are subject to outbursts, unquestionably movements of some kind have taken place, as shown by faults, folding, and similar evidences of former stress. Some students of outburst phenomena believe that this stress is still active, in fact, outbursts have been attributed to its existence (42, 51, 68), either in whole or in part. The cluster theory requires that these movements of strata not only have crushed the coal within the cluster but have rendered it more compact without, thus forming a retaining wall relatively impervious to gas.

Some authors have postulated rather high and almost impossible values for the magnitude of the gas pressure within the cluster, while others believe that rather low pressures suffice to explain most outbursts. In view of the great variation in violence exhibited by these occurrences, even in the same locality, it is reasonable to suppose that the gas pressures acting at the time also vary considerably. Other variables are the size of the cluster and the volume of gas associated therewith. Graham has suggested 10 atmospheres (32, p. 117) as a maximum and Rice (74, p. 134) the same pressure as a minimum to explain the physical effects of the outbursts considered by them. Ruff (88, p. 305) has made a lower estimate and Roblings (81, p. 109) still lower one. The latter value must be interpreted as the minimum requisite pressure difference over a distance of several feet in the passageway during some part of the outburst interval and not as the pressure in the cluster before the outburst. As stated previously, measured gas pressures much higher than these estimates have been reported in normal coal.

Although the prior existence of clusters may be the true explanation for some outbursts, it appears unjustifiable to rule out the possibility that other factors sometimes contribute. Instances have been reported (41, 45, 63) in which considerable coal, accompanied by moderate or negligible quantities of gas, was shattered and thrown into the workings. These outbursts have been definitely attributed to forces other than gas pressure. It therefore seems only logical to suppose that some outbursts are the result of a composite of several factors.

Adequacy of Sorption Theory

In a discussion of the adequacy of this theory it is unfortunate that one cannot assume that all the gas "made" in a coal mine comes from the coal broken down in mining. It is still more unfortunate that one often does not know what fraction of it comes from the broken coal or even from the bed.
itself in the immediate neighborhood. Sometimes, particularly in the more
gassy mines, the quantity of gas apparently is independent (47) of the mining
activity. Obviously the greater part of the gas must come from sources en-
tirely foreign to the coal near the face. For mines that show (12, 39, 47)
a decrease in the quantity of gas when mining operations are curtailed
the decrease must bear some relation to the effect of the mining operations upon
the gas content of the coal or upon the depth of the drainage belt. The
latter is improbable if this depth is ordinarily rather great. If a large
fraction of the coal is left underground the decrease in evolved gas would not
be a fair estimate for the gas in the mined coal; but it still might be a
reasonable estimate for all the coal originally in the affected area—that is,
the sum of the mined and unmined coal. Moreover, if such estimates are to
indicate the gas content of the virgin coal it must be assumed that the gas
drains readily from the coal affected by the mining operations.

If a good fraction of the gas evolved came from outside the bed or from
a great distance within the bed, obviously any discussion of the original gas
content of that particular coal, based upon the actual quantity of gas "made"
in a mine in that bed, is valueless. For such beds some mode of reasoning is
necessary which includes variations in gas evolution with changes in coal
production. Considerable data are available on the subject of gas evolution
in mines, but very little of it can be interpreted in this manner. Even when
this interpretation is possible it is based upon so many inherent assumptions
that the treatment admittedly is not as rigorous as might be desired. For
instance, some of Clive's data (2) indicate a decrease of at least 30 percent
in methane production due to cessation of mining operations. Assuming that
all the decrease was due to the gas which was originally in the coal removed
in mining, and choosing 1,200 cubic feet of gas per ton of coal mined (a very
conservative figure for the case treated) as the normal evolution when the
mine was being worked, about 400 cubic feet of gas could be attributed to each
ton of coal. Actually, this assumption is invalid, since some of the gas
doubtless came from the coal left underground. Hence, in the absence of in-
formation upon this point, 300 cubic feet per ton (or 940 cm$^3$ per 100 grams)
may be taken arbitrarily as the original gas content of all coal. On the
basis of the sorption data that have been cited, it may be seen that the
pressure in the original bed must have been at least 20 atmospheres.

On the other hand, suppose one could assume: (1) That most of the gas
did come from within the bed (46, 67); (2) that the extent of the drainage
area did not extend more than a few hundred feet beyond the face, and (3)
that the amount of coal—the gas content of which is altered in any way by
the mining—is essentially constant for a given face area over a reasonable
period. Then the ratio of the total gas production (corresponding to constant
coal production) to the total weight of the coal originally within the proper
increment of the mined "area" should closely approximate the original gas
content of the coal. Probably the second assumption has less chance of being
valid than either of the other two. It can be valid only if the gas pressure
in the bed is rather low or if the coal bed is almost impermeable to the gas.
In the latter case it would be necessary to determine what fraction of the
total gas content was evolved by the broken coal and that left in the mine.
Previous attempts at correlating gas production and sorption data tacitly
make the above assumptions.

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The amount of gas actually evolved in some exceptional mines is quite large (13, 39, 47; 78, p. 329; 93, p. 115) -- 1,500 to 8,000 cubic feet of methane per ton of coal mined, or 4,000 to 25,000 cm³ per 100 grams of coal -- but in most mines the evolution is much less. If reasonable pressures are assumed for the virgin seam, then the extent to which these larger gas evolutions are amenable to the theory depends upon the fraction of the coal left underground and the extent to which the gas escapes therefrom. If the coal contains 1,200 cm³ of gas per 100 grams as a maximum, and if 90 percent of the coal (78, p. 343) is not removed, it would seem that about 12,000 cm³ of gas per 100 grams of mined coal would be about the limit to which the theory applies. If less coal is left underground or if all the gas does not escape from the coal, this limit becomes still smaller.

On the basis of this limit it may be seen that there are a few mines in which one or more of the above basic assumptions are not tenable. In these the depth of the drainage belt was either very great or the gas came from outside the bed. Budge (9) has discussed the latter possibility in considerable detail for a particular coal field. It is his belief that the gas seeps into the workings from other coal beds and/or from carbonaceous shales. The data cited by Budge and by Graham (35) show that generally the shales are relatively poor absorbents for methane.

Still another means of testing the theory exists in the meager and rather unsatisfactory data on gas outbursts. The quantity of gas evolved during the outburst interval and shortly thereafter might approximate the real quantity of gas contained in the virgin coal (figured on the basis of the disturbed coal after the occurrence) more nearly than does the quantity of gas evolved under normal conditions of mining. Of course this conception tacitly assumes that the outburst took no blowers or pockets of gas within or without the bed and that very little gas has escaped from within the cluster prior to the outburst. It assumes further that the gas content of a given potential cluster in the virgin seam was the same as that of the normal coal. The validity of this distinction as to the relative exactness with which the two modes of gas evolution (normal or continuous evolution and the "instantaneous" gas outburst) correspond to the original gas content of the virgin bed depends entirely upon the correctness of the assumptions associated with the discussion on each kind of gas emission.

Unfortunately the various quantities of gas liberated by the major outbursts of the past are not known accurately. All of the estimates appear to be little more than reasonable guesses (in general, the estimates for a given case do not differ by more than a factor of 2 or 3), but as a rule the lower estimates (4; 78, p. 341) at least are amenable to the sorption theory if rather high initial pressures are assumed. This is as it should be, for the theory, if correct, must be capable of explaining the gas evolution in all outbursts, provided no gas extraneous to the disturbed coal is drained off at the same time. In the few instances in which the theory does not appear adequate the outbursts must have tapped some nearby gas reservoir or else the estimates of the gas volume were not correct. For example, the exceptional outburst referred to by Briggs (4) in which approximately 12,000,000
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cubic feet of methane escaped and 420 tons of coal were thrown out, certainly cannot be explained on the basis of gas sorbed by this quantity of coal. Conversely, in the vast majority of outbursts the various quantities of gas associated with them are readily interpreted in terms of the theory.
SUMMARY

1. The recent literature on the occurrence of gas in coals has been reviewed and the present status of the situation discussed critically wherever feasible.

2. Pertinent information concerning the origin of the methane or carbon dioxide often found in coal seams has been reviewed. The consensus of current opinion is that the methane was generated within the coal bed and the carbon dioxide came from without the bed. If the latter is true the carbon dioxide probably is formed simultaneously with new minerals by the action of hot solutions of the constituents of intruded magma upon adjacent carbonates. There appears to be no necessity for assuming an exterior source for the methane. More evidence is necessary to substantiate fully any theory as to the origin of either gas.

3. Information available on the ethane content of coals shows that generally there is a smaller percentage of ethane in coal, relative to methane, than in most natural gases. If the hydrocarbon gases in coal came from natural gas, apparently the latter must have been deficient in ethane.

4. A few hitherto unpublished analyses of some gas samples obtained from coal samples or from firedamp have been included. Gas from a New Mexico mine contained as large an ethane percentage as many natural gases. Gas collected in a British Columbia mine showed about 0.2 percent ethane. The gas evolved by coal samples from this same mine when ground under reduced pressure contained about 60 times as much ethane as that evolved in the mine.

5. Available experimental data on the sorption of compressed methane or carbon dioxide by several coals have been summarized and discussed. In addition, sorption data are presented for single samples of American subbituminous, bituminous, semibituminous, and anthracitic coals, methane being the sorbate. These data indicate a rough relationship between the sorptive capacity of a coal and its rank, the capacity increasing with increase of rank at least to the anthracite range. Within the possible experimental error the capacity of a given sample is independent of the size of its particles at equilibrium; however, the rate at which the gas is picked up is a function of particle size. Even for coals having low moisture contents the sorptive capacity is increased considerably by partial drying. The sorption of carbon dioxide is roughly twice that of methane, other factors being the same.

6. An attempt has been made to treat the evolution of gas from an ideal coal bed to clarify the situation for actual beds. At least two factors control the evolution of gas from a given seam:

a. The effective permeability of the coal itself as well as adjacent strata. This refers to the flow through crevices large enough for viscous gas flow.

b. The pressure gradient back of the coal face. This may extend over much greater distances than usually is intimated.
Possibly there is a third factor (if a good fraction of the gas evolved in the mine was originally sorbed in the coal not very far back of the face):

g. The gas content of the coal.

7. Instantaneous outbursts of gas are unknown in the vast majority of coal mines. They occur, rather infrequently for the most part, in several restricted mining areas, all outside the United States. They vary greatly in violence; the more violent outbursts have occurred in beds which have been disrupted by strata movements in the past ages. The worst outbursts do not occur necessarily in mines in which the phenomena are most frequent. There seems to be no relation between the frequency of outbursts in the affected regions and the gas pressure in the beds, the depth of the beds, the rate of gas evolution, or the composition of the gas. Outbursts are thought by most observers to originate in so-called "clusters" or "nests". These are pictured as bodies of sorbed coal, containing sorbed gas under some pressure, which are surrounded by a wall of highly compacted and impervious coal. When this wall is weakened by mining the pressure ruptures the wall and the fine coal and gas rush out. This theory seems sufficient for most purposes, although it still lacks experimental verification.

8. The limitations of the sorbed-gas theory as an explanation of the normal gas evolution in mines, as well as that during gas outbursts, have been presented in an effort to clarify the situation. Three methods of approach have been outlined on the basis of: (a) the decrease in gas flow with cessation of mining, (b) the normal gas flow, and (c) gas emission during the outburst interval.

The first method is applicable to mines in which cessation of mining operations causes some decrease in the evolution of gas but in which a good part of the gas evidently comes from sources foreign to the coal near the face. (For gassy mines in which curtailment of mining operations does not influence appreciably the gas evolution no method is available for estimating the gas content of the virgin coal in that locality, unless sorption data are available and the gas pressure in the bed is known.) In applying this method one must assume that the decrease in evolution of gas is due entirely to the non-emission of gas (while the mine is inactive) by the coal, which ordinarily would be affected by the mining operations. Hence this method is at best a makeshift. Such an analysis of Clive's data indicates a pressure of at least 20 atmospheres in the coal about a specific mine. This is not an unreasonable value, as pressures higher than this have been measured in other coal beds.

The second method of approach is likewise an approximation, since it depends for its successful application upon several assumptions, none of which is ever completely valid in all probability. If most of the gas content of the coal affected by the mining operations escapes in the mine and if more than 90 percent of the coal is removed, the theory is incapable of explaining indicated gas evolutions in excess of 12,000 cm³ per 100 grams of mined coal. (This assumes that 100 grams of virgin coal does not contain more than 1,200 cm³ of gas at the gas pressure in the bed.) There are a few mines in which
this limit is exceeded. Hence, the virgin coal contains more than the assumed quantity of gas, or else the gas came from a distant source.

The third method depends upon the gas evolved during an outburst. It also involves several assumptions, all of which ought to be approximately valid if the ordinary picture of the cluster is correct. The principal difficulty with this method lies in the inherent inaccuracy of the estimates of the quantity of gas evolved. On the basis of the quantity of coal blown out, some estimates are absurd, but most of them are amenable to the theory.
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