Economic Geology, v. 2, pp. 225-241

ECONOMIC GEOLOGY

WITH WHICH IS INCORPORATED

THE AMERICAN GEOLOGIST

VOL. II APRIL–MAY, 1907 No. 3

THE COMPOSITION OF COALS.

FRANK F. GROUT.

INTRODUCTION.

The chemical nature of coal is rapidly becoming better known, and it occurrs to the writer that graphic representation of such reliable analyses as are at hand may suggest some interesting comparisons. The work of Mr. Iddings in presenting diagrams of rock analyses has proved of such value that the application of similar methods to coal analyses is presented in this paper with the hope that it may render clear some questions not heretofore perfectly understood and stimulate other workers to elaborate the material at their disposal.

An arrangement of this kind indicates that the coals of our new State of Oklahoma are of excellent quality, and this was one of the main objects of the study. The coal thus far tested by the U. S. Geological Survey shows Oklahoma coal to be above the average; yet the best coals have not been tested.

In this paper the work of other writers has been freely used, especially those of the U. S. Geological Survey and Professor S. W. Parr, of Illinois. Thanks are due to Professor Charles N. Gould and the University of Oklahoma for many kindnesses.

In the literature available the writer has found no attempts at the representation of coal by diagrams except those of Professor Parr[1] and a rough inaccurate diagram by Newberry to show the

[1] University of Illinois Studies, Vol. 1, No. 7.

process of alteration from cellulose to graphite. Professor Parr first made use of concentric circles one of which represented the ultimate and another the proximate analysis; and with a very little study, these gave a clear idea of the value of a coal. No attempt was made to arrange these in a multiple diagram. Recently the same author has made use of rectangles and the arcs of circles to make clear the composition of the volatile matter.[2]

CONSTRUCTION OF THE DIAGRAMS.

The value of a diagram depends first on the clearness and the readiness with which its meaning can be grasped and retained, and second, on the purpose of the diagram. In selecting a graphic representation of the four parts of a proximate analysis, the division of a circle by radii does not produce so clear and strong an impression as an arrangement of triangles. No arrangement can be found, in which lines (distances) being made in proportion to the analytical data, the areas will be readily intelligible. Equilateral triangles have therefore been used, such that the areas are proportional to the four constituents as shown by the proximate analysis. Fixed carbon is represented by a central white triangle, volatile matter by a black triangle placed just above; ash by a black triangle below to the left; moisture by a black triangle below and to the right (see Fig. 25). This makes a series of figures quite distinct in different parts of the coal series. By the diagram the character of the variation in proximate constituents can be seen at a glance, and the impression given is clearer than any obtained from a table of analyses.

To further show the chemical composition of the coals, it is instructive to arrange them in a multiple diagram, based on the ultimate analyses. The essential part of the coal is here considered to be the sum of carbon, hydrogen and oxygen. Nitrogen and sulphur, combined with carbon, are subordinate and not considered as affecting seriously the nature of the hydrocarbon compound. By thus using three elements, it becomes possible to represent the amounts of all by a single point in a triangular

[1] Illinois Geological Survey, Bull. 3, p. 33.

diagram (see Fig. 23). If at this point an individual diagram is constructed, all the analytical data can be seen at a glance, except the sulphur and nitrogen. The writer has made no attempt to show these points, though for practical purposes sulphur is of extreme importance, and it might be added to the individual diagram with no great complication.

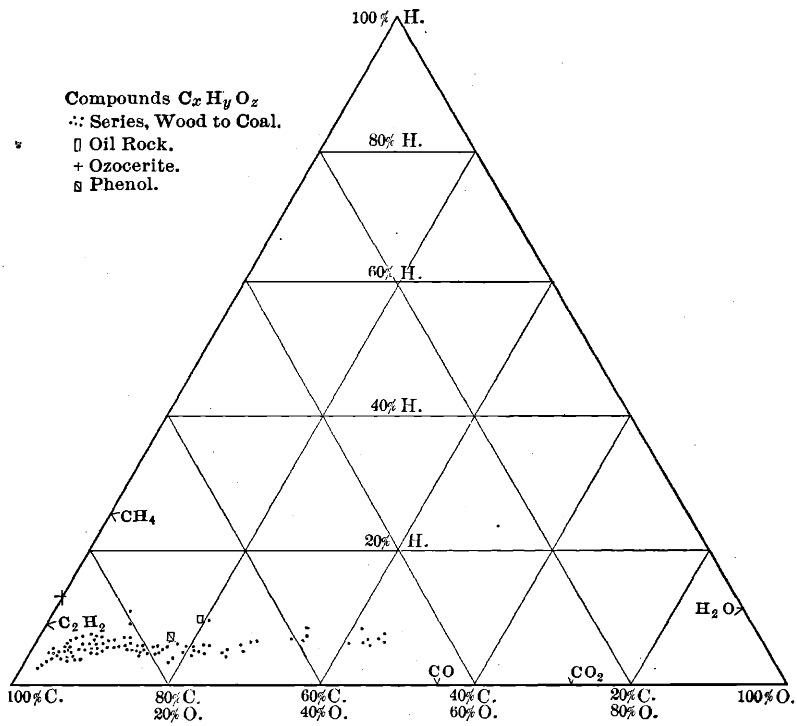

FIG. 23. Hydrocarbon compounds.

In arranging the multiple diagram all analyses are recalculated to 100 per cent. of carbon, hydrogen, and oxygen, leaving out the moisture, which cannot be part of the hydrocarbon. This makes the analyses comparable on a definite basis, besides making it possible to show the three elements by a single point.

Figure 23 shows the whole range of possible combinations of the three. It is not large enough for the introduction of in-

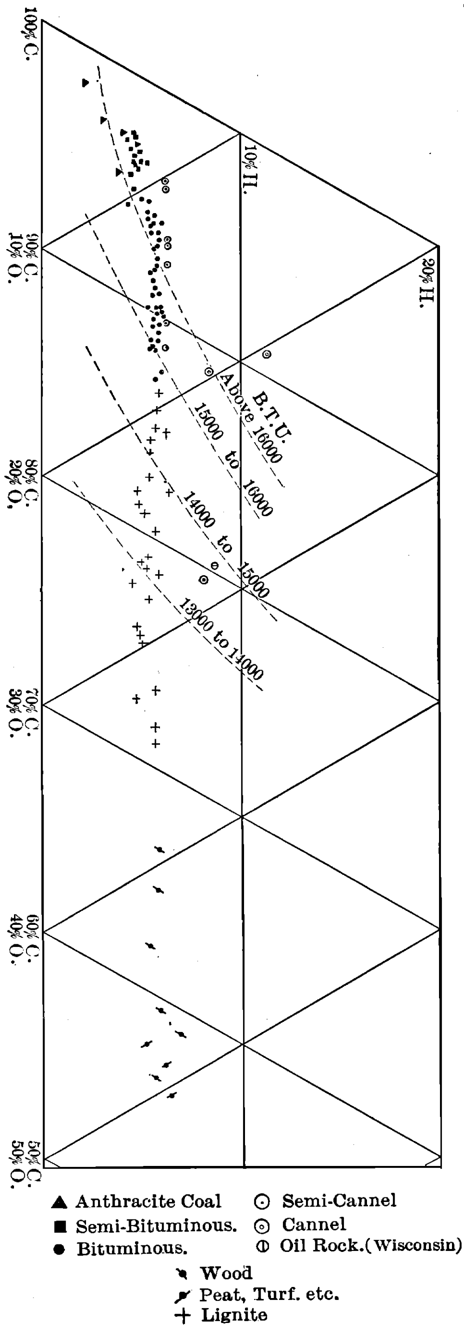

FIG. 24. The coal series.

dividual diagrams. Graphite and diamond lie at the lower left corner; hydrogen at the top; and oxygen at the lower right. Pure hydrocarbons lie on the line from 100 per cent. C to 100 per cent. H. The oxides of carbon lie on the base line. Water and hydrogen peroxide are on the right border. As plants form the source of so many hydrocarbon compounds, it is of interest to note the position of cellulose—just below the center. Other plant products have rather different composition and the variation is suggested as the reason for some varieties of coal. Most of the dots represent the coal series; but some common compounds lie in the same position in the series; as, for example, phenol, one of the products of the distillation of coal.[1]

Fig. 24 shows the coal series enlarged from Fig. 23. Coals of different type by reputation in the market are shown by different symbols.

In Fig. 25 some scattered examples from the series are shown in the combined diagram. The whole series of available reliable analyses could not be clearly presented in this form on a sheet much smaller than four feet long, but makes a very instructive diagram.

Fig. 26 contains a result of the study of the preceding and will be discussed below.

PURPOSE.

The main purpose is, of course, the simple graphical comparison of the chemical analyses of coals in such a form that one may see at a glance the relation of a sample to the whole series, and the common range of variation. The gradual nature of the variation in all directions, the fact that there is no break in the series from wood to graphite, from lignite to cannel, and the interesting nature of the extremes of the series, are clearly brought out, as is the fact that most of the analyses available are of bituminous coals. In this connection the diagrams furnish good graphical argument as to the origin of coal.

[1] The construction would have been simpler, but the diagram less clear, if two of the constituents had been plotted between rectangular coödinates. When two are thus shown, the third could always be found, as 100 per cent. minus the sum of the two.

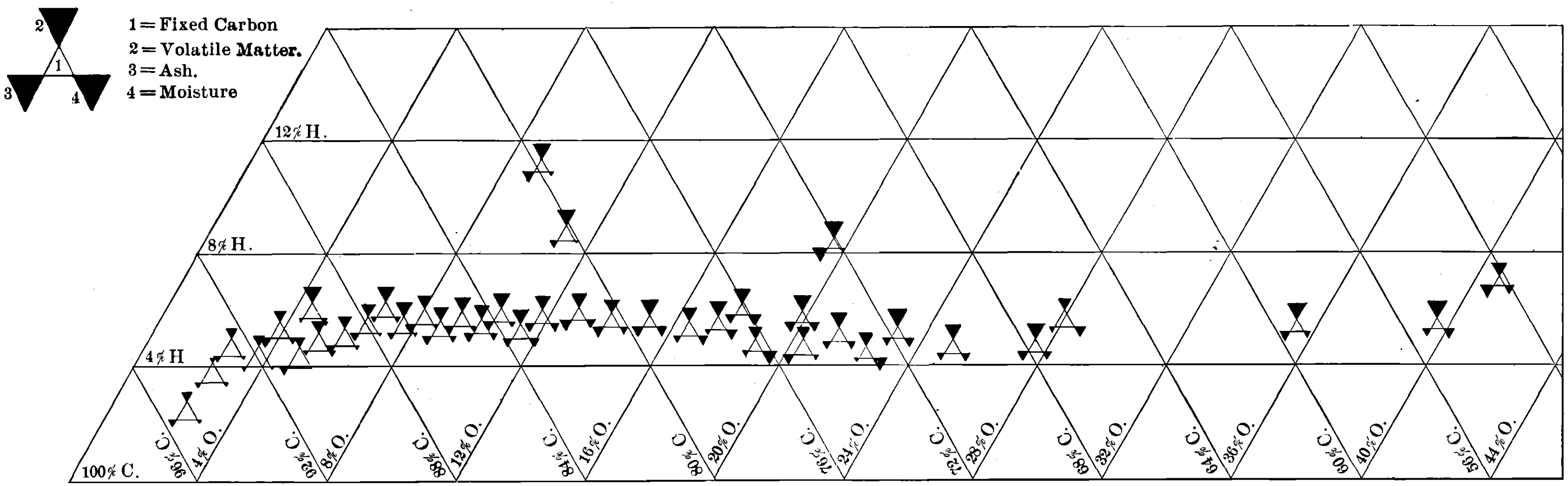

FIG. 25. Coal diagrams.

The gradual chemical change has long been noted, but the diagrams show it at a glance.

Some further points were brought out, though not altogether responsible for the construction of the diagram, such *e. g.*, as the constancy of the per cent. of hydrogen. This may have some bearing on the reactions in the metamorphism, oxygen being the heaviest loser. The average per cent. of hydrogen from wood, over to semi-bituminous coal is 5.64 ± 60 the average error being 0.30 per cent. and smaller if confined to the bituminous alone. In a single coal basin or single seam, the error might be reduced. In the large number of Illinois coals (21) tested at St. Louis, the average is 5.67 per cent., with an average error of 0.22 per cent. The uselessness of any further calculation of available hydrogen is apparent.[1]

The final value of the figures is the light they throw on the matter of the classification of coals.

ANALYSES USED.

The larger part of these are from the results of the U. S. Geological Survey. All the analyses of coals, tests of which are reported in Professional Paper No. 48, are used; and a few from Bulletin 290, where they would fill any gap in the series. These are taken as representing the most modern and exact results possible, though there is evidence that no compensation has been made for the error due to the oxidation of the iron of pyrite which is weighed in ash as Fe_2O_3 and may affect the figure for oxygen by as much as 2 per cent. The lignite analyses published by E. T. Dumble[2] have been quite freely used. The report of Michigan coal, by Lane[3] was also used. Some analyses of cannel were taken from Thomas's book "Coal Mine Gases and Ventilation."

[1] These errors are less than 4 per cent. of the total hydrogen. Professor Parr's elaborate calculation in Bull. 3 of Illinois Geological Survey gives results that vary by 5 per cent. in Illinois coals alone and much higher in some cases.

[2] Geol. Surv. of Tex. Rep. on Brown Coals and Lignites of Texas.

[3] Michigan Geological Survey, 8, 110.

In Fig. 2 an attempt was made to enclose all coals of similar fuel value in groups by dotted lines, using, for the purpose, the fuel value of ash- and water-free coal. The highest values were not for the last stage in the metamorphism. This brings up a question in classification. Which should be given first place—the coal of best fuel value, or the most metamorphosed coal? Inasmuch as it is commonly known that anthracite has not so high a fuel value as some other coals, it seems unnecessary to place it with others of so different a character as those of similar fuel value. It was noted at once, however, that the fuel value of the hydrocarbon of limited fields is not constant as some have attempted to show.[1] If any such relation exists between hydrocarbon and fuel value, the field must be more restricted than the "Oklahoma field" or "the Illinois field" where variations reach nearly 5 per cent. Professor Parr[2] in his calculation of "true fuel" and "gross coal index" implies that the fuel value of $C + (H - o/8)$ can be calculated, but this is just as uncertain, and seems to depend on the method of combination of the hydrocarbon.[3]

The purpose of the diagrams has been outlined and it is thought that they will be quite self-explanatory. The bearing of the figures on the classification of coals, however, needs some detailed study. The material of the analyses seems to be quite similar to that published long ago, but as recent writers on classification seem to have lost sight of several facts, the diagrams may help to set things right. Misconceptions have arisen which might have been avoided by a study of the literature, even before the large amount of work by the U. S. Geological Survey.

[1] *Jour. Am. Chem. Soc.*, Vol. XXVIII., p. 1430.

[2] Lane, Michigan Geol. Survey, VIII., p. 87.

[3] A rough attempt was also made to group all good coking coals in a manner similar to that used to group coals of similar fuel value. But there are too many variables, and the coking is not dependant entirely on the hydrocarbon, but also on the ash, and the method of coking.

CLASSIFICATION.

First, it must be evident that there are no natural groups, and any group designated must be limited quite arbitrarily. Second, as it is the general market which will eventually decide whether any classification suits its needs, we may consider in a word, the commercial classification. This is based on the physical action of a coal in the fire. Griffith[1] even questions the use of fuel ratios in proof of anthracite, saying that these coals, and only these, burn *without smoke*. And Dr. H. F. Bain suggests that the only proof of a lignite is, that if charged into a locomotive fire-box, it all goes out the stack. These properties are variable in any coal and determination depends too largely on the personal factor. Even the U. S. Geological Survey call their sample Montana No. 1 a coal in one place and a lignite in another. Moreover, there is a complete gradation between the classes. Dumble mentions[2] several other physical properties, but none are more definite. Such are the commercial methods and it would be quite surprising if any scientific method could possibly be made to conform to this determination.

Turning to chemical methods we find various suggestions, quite recently in particular. The early fuel ratio[3] disagrees with the commercial, too seriously to be satisfactory in discussing the lignite series. Collier and Hayes,[4] after finding that geological age would not distinguish lignites, let the matter rest with fuel ratio and water, both being involved. W. D. Smith follows this plan, letting more than 10 per cent. moisture distinguish lignites.[5] He refers to Grüner as using a ratio O + N; H, which is similar to some mentioned below, but quite complex. Both Dumble[6] and recently Campbell[7] have shown that moisture is not a safe distinction for lignites. Campbell then discussed

[1] *Mining Magazine,* XIII., p. 214.
[2] *Loc. cit.,* p. 48.
[3] Frazer, *Trans. A. I. M. E.,* VI.
[4] U. S. Geol. Survey, Bull. 218.
[5] Bull. 5, Mining Bureau, p. 44. Dept. of Int., Manila.
[6] *Loc. cit.*
[7] U. S. G. S. Professional Paper 48, p. 157.

the results of tests of coal at St. Louis, using for his arrangements, fuel ratio, fixed carbon, carbon, hydrogen, and the ratio of carbon to hydrogen. In most of this work the hydrogen of moisture is included. This seems absurd. The order of arrangement is entirely changed by omitting it. The carbon-hydrogen ratio which he finds most satisfactory fails utterly and the reason can be seen by a glance at figure 24. Although the hydrogen of lignites and bituminous coal is not much different, the range in each amounts to nearly a third of the total. When the per cent. of carbon is divided by this variable, it is to be expected that coals of similar quality will give quotients varying by 25 per cent. or more. Parr remarks that the use of hydrogen is "illogical" without explanation. But if Mr. Campbell had excluded both moisture and ash, in his arrangement, based on total carbon, he would have found an excellent separation of coal and lignite. This is also seen in a glance at Fig. 24. In spite of the complete gradation from wood to graphite, it is possible to draw a line on the diagram, such that no coal will be on the right of it, and no lignite on the left. Still more remarkable, the line may be inclined so as to represent a per cent. of carbon or, in the other direction, so that it represents a certain per cent. of oxygen. More complete lists of analyses may develop some cases where a coal known in the market as bituminous, will fall on the lignite side, or *vice versa,* but *none have yet come to our notice.* The fact that both carbon and oxygen are capable of distinguishing lignites, is a result of the comparative constancy of hydrogen.

The use of oxygen in this way is not at all new, though the recent writers have not seemed to be aware of it. Dana's Mineralogy informs us that bituminous coal contains 5 to 15 per cent. oxygen (rarely 16 or 17), ash excluded, while lignites, *dry,* contain 20 to 36 per cent. F. P. Dewey[1] says brown coal is one of the subdivisions of bituminous coal, "but more highly oxygenated than any of the other coals, containing 15 to 30 per cent. oxygen." Dumble[2] refers to some work by Cappacci

[1] Bull. 42, Smithsonian Institute.

[2] *Loc. cit.,* p. 33; 1892.

on Italian lignites, which seems very good. Dumble gives the following, though he does not use it except as a distinction for lignites.

$$C:(H+O) = 1.0 \text{ in wood.}$$
$$C:(H+O) = 2.3 \text{ in lignite.}$$
$$C:(H+O) = 5.6 \text{ in bituminous coal.}$$
$$C:(H+O) = 19.0 \text{ in anthracite.}$$

In spite of these references (where oxygen is used), which are available to the U. S. Geological Survey, Campbell tries only carbon, hydrogen, and fuel value and says these are "all the elements upon which a classification can logically be based." Carbon would be good, if he had not included moisture, but if he did not find it so, oxygen was as good as in years past. Professor Parr makes much of "inert volatile matter," saying its only recognition thus far seems to be in Dulong's formula. It is the well-known oxygen which determines the amount in inert volatile which is practically no more nor less than 9/8 oxygen, or water. He seems to consider it a new distinction, but if oxygen is distinctive 9/8 oxygen should be equally good, only more complicated. An effort seems to have been made to let a single ratio determine the place of a coal in the classification. But the diagrams show the difficulty. Coal varies in three directions, and at least two independent variables are needed to classify it. A single ratio would always place cannel coals with others of very different quality. Analyses of cannel are scarce. But the writer's own work on Illinois cannel[1] and again on some Brazilian turf, for Dr. I. C. White, fill in some gaps in that part of the series. Professor Parr's is the only classification yet proposed which can furnish a place for cannel. If he would introduce between his groups C and D a group

$$\text{"E . . . Cannel} \begin{cases} VC \times 100/C = 40 \text{ per cent. up} \\ \text{inert volatile 5 to 10 per cent.,"} \end{cases}$$

[1] Credit should be given Doctor Bain and the Illinois Geol. Survey for whom the work was done.

it might well represent cannel,[1] but simpler relations are easily found.

THE LOGICAL CLASSIFICATION.

Both the proximate and ultimate analysis give data from which variations in coal may be noted, but in recent study it is becoming ever more clear that the former alone is not sufficient in all cases. The use of the ultimate analysis alone was not a success as tried by Mr. Campbell. Professor Parr uses both proximate and ultimate with some complication, the value of which may be questioned. Two main points should be considered in selecting data for classification. First, the results *should distinguish* the groups and show a considerable range beween the groups. Second, the data should be simple and easy and accurate of determination. Professor Parr's "inert volatile" is complex, difficult, and inaccurate. His new ratio does no better than the old fuel ratio. To emphasize this point let us repeat, the simplest accurate way to relegate a coal to the group "anthracite," for example, is the one to use; for when we say it is an anthracite no one thinks of a coal with any other properties than those of anthracite. There are many points which would determine it. The diagrams show carbon high, hydrogen low, oxygen low; hence, carbon-hydrogen ratio high, carbon-oxygen ratio high; also, fixed carbon, high, volatile matter low, fuel ratio high, etc., etc. When one says anthracite, all these things are necessarily included. The determination of the fact that it is anthracite does not need any *certain one* of the points any more than the public need to be told that anthracite does not smoke. It is understood. Similarly, with the other groups. The simplest accurate points make the best classification.

Fuel ratios are simple, but do not distinguish cannel, lignite, and bituminous coals. It is necessary to introduce some data from the ultimate analysis. If it is desirable to base the whole thing on ultimate analysis, this could be done by the use of the points above suggested for the distinction of anthracite, and some other, like carbon or oxygen, for the distinction of lignites. But this restriction to the ultimate, does not seem necessary. The proximate really gives the best distinction for high-carbon coals.

[1] *Jour. Am. Chem. Soc.,* XXVIII., p. 1429.

What point, then shall we select as the distinction for lignites? There is a possibility that it may be found easier to determine total carbon in a coal without a complete analysis. Numerous pieces of apparatus have been put on the market in the last few years for carbon estimation, without reference to other constituents, and the writer would recommend carbon, if accurate, as a basis for the distinction. Parr uses this carbon estimation to calculate "inert volatile" by a method which varies as his study of coal proceeds. He does not claim great accuracy for the determination and, as already mentioned, carbon itself is a good and sufficient distinction; certainly, more accurate than a figure estimated from this and a couple of other variables. Oxygen would be as good if a complete ultimate analysis is at hand (see Fig. 24). The carbon-hydrogen ratio fails. Taken in connection with fuel ratio, total carbon makes a satisfactory classification.

But now it is time to question whether the fuel ratio is best for high carbon coals. It is so well known that it may be useless to discard it. However, it seemed simpler to use the per cent. of fixed carbon in the hydrocarbon. The two variables are then of the same type; viz., fixed carbon of the pure coal, and total carbon of the pure coal. To avoid the ultimate analysis, one must consider the pure coal as the sum of fixed carbon and volatile matter instead of the sum of carbon, oxygen, and hydrogen. This does not alter the arrangement of coals except in case of New Mexico coals, and one sample from Iowa. These are near the border line.[1] This is the classification presented at the close. It is to be noted that each figure for a per cent. of fixed carbon might be replaced by a certain fuel ratio, for the volatile matter is 100 per cent. minus the fixed carbon, and the

$$\text{fuel ratio, therefore} = \frac{\text{Fixed Carbon.}}{100 - \text{Fixed Carbon.}}$$

In this discussion the matter of simplicity has predominated.

[1] Campbell describes the New Mexico samples as coal, in the field, but classifies them as lignites, as they seem to be. One Iowa coal has the same carbon-hydrogen ratio, however.

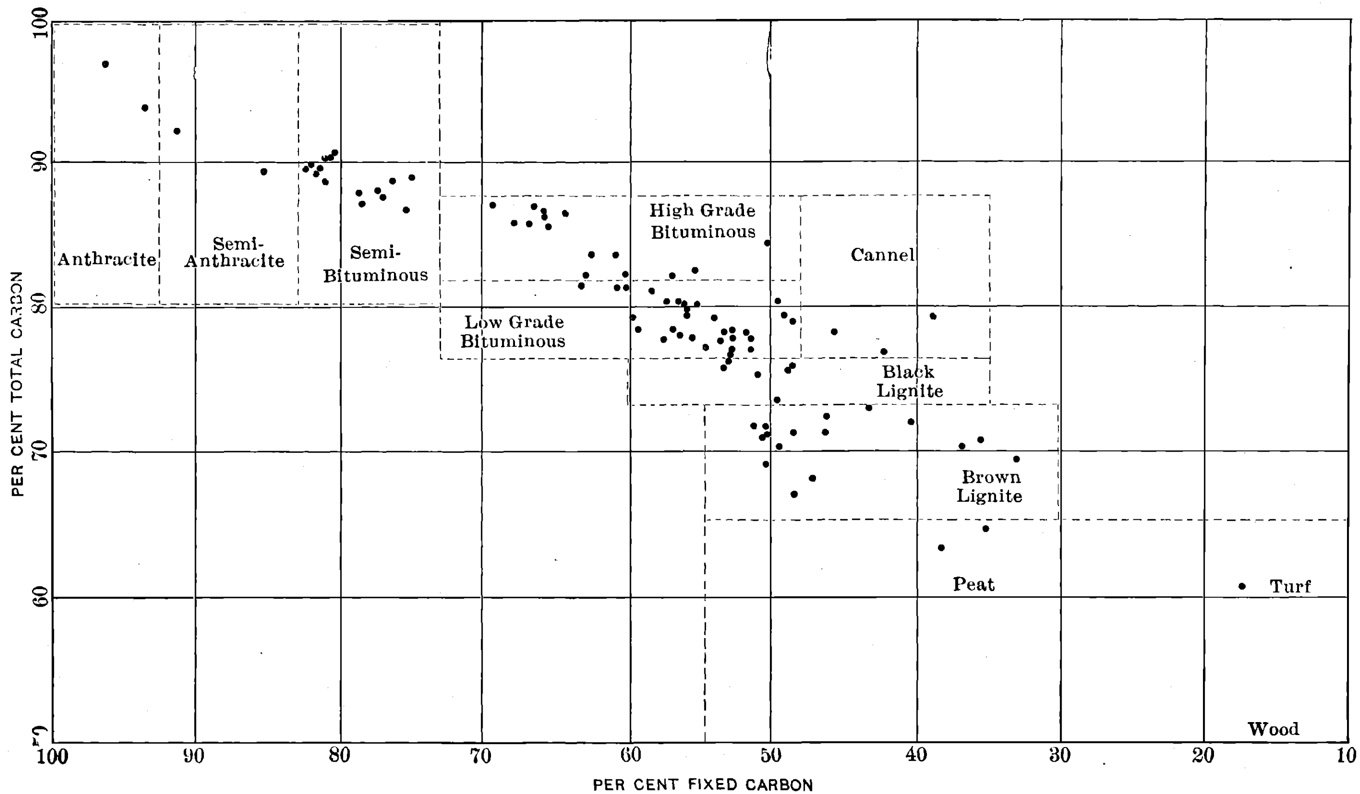

FIG. 26. Diagram of proposed classification.

The range is equally satisfactory; fixed carbon varying from 99 to 9; while total carbon varies from 99 to 50. Oxygen which has been used shows a very good range, but it is determined "by difference" and cannot be better. No other factors show a greater range. Then why offer the more confusing or more inaccurate ones?

The classification at the end of this paper is shown diagrammatically in Fig. 26. Bituminous coals are divided into two groups on the basis of total carbon. They might well be again divided on the basis of fixed carbon, as those at the right of the group approach cannel coals, and are already known in the market as "semi-cannels." These include some from Michigan and Missouri. A line along 51 per cent. fixed carbon would separate them into a small group, the relation of which to cannel is apparent. The groups known as peat, turf, and oil-rock, overlap each other and wood, probably on account of the variable nature of wood. The brown lignites are well distinguished from black.[1]

In conclusion two points should be emphasized. First, the well-known fuel ratio can be substituted, point for point, in place of the fixed carbon of the classification, making no change in the result. This means that the present classification is used as a basis and the addition of a simple carbon determination makes it complete.

Second, the arrangement may seem scientific rather than practical, but can easily be translated into an everyday meaning. The writer is certain that if it be said that a coal is "cannel because it has 40 per cent. fixed carbon and 80 per cent. total carbon in the pure coal," no one will think of coal of any other properties than those of cannel. It is completely defined as to fuel ratio, carbon-hydrogen ratio, etc. Similarly with all the groups presented.

It may be that at some time the limits assigned these groups may be somewhat altered, but they now seem quite definite and well-fixed.

[1] Since this line between black and brown is so sharp, and that between black lignite and coal so ill-defined, it might be well to class the black lignites as low-grade bituminous; they are really a small group. Still they have physical properties of other lignites, like decrepitation.

SUMMARY.

All the chemical constituents of coals (except nitrogen and sulphur, which might be added) are shown graphically in a multiple diagram to indicate the general relationships of the coal series.

The character of the variation is well displayed and the variation is not a linear one, as the series ranges in two directions.

The bearing of the diagrams on the classification of coals is mentioned.

The logical classification is sought and a sample is here presented. The data used are the fixed carbon in pure coal and total carbon in pure coal; *i. e.*, ash- and water-free coal (see Fig. 26).

CLASSIFICATION OF COALS.

Graphite	Fixed carbon over 99 per cent.
Anthracite	Fixed carbon over 93 per cent.
Semi-Anthracite	Fixed carbon 83 per cent. to 93 per cent.
Semi-Bituminous	Fixed carbon .73 per cent. to .83 per cent.
Bituminous:	
High Grade	Fixed carbon 48 per cent. to 73 per cent. Total carbon 82 per cent. to 88 per cent.
Low Grade	Fixed carbon 48 per cent. to 73 per cent. Total carbon 76.2 per cent. to 82 per cent.
Cannel	Fixed carbon 35 per cent. to 48 per cent. Total carbon 76.2 per cent. to 88 per cent.
Black Lignite	Fixed carbon 35 per cent. to 60 per cent. Total carbon 73.6 per cent. to 76.2 per cent.
Brown Lignite	Fixed carbon 30 per cent. to 55 per cent. Total carbon 65 per cent. to 73.6 per cent.
Peat and Turf	Fixed carbon below 55 per cent. Total carbon below 65 per cent.
Wood	

As an example of the calculation, one will suffice,[1] Indian Territory No. 2. The analysis is:

Moisture	1.70 per cent.
Volatile matter	37.19 per cent.
Fixed carbon	49.79 per cent.
Ash	11.32 per cent.
Total carbon	71.49 per cent.

The pure coal is, therefore, 86.98 per cent. and in the pure coal, fixed carbon amounts to 57.25 per cent. while total carbon

[1] U. S. Geol. Survey Prof. Paper No. 48, p. 215.

is 82.17 per cent. The figure for fixed carbon might place it with high or low grade bituminous coal, or black lignite, but the figure for total carbon places it with high-grade bituminous coal. A few applications to domestic coals are given below:

APPLICATION OF CLASSIFICATION TO COALS OF UNITED STATES.

Name of Sample.	Locality.	Fixed Carbon (in pure coal).	Total Carbon (in pure coal).
Anthracite.			
Pennsylvania No. 3.	Scranton.	91.09	92.18
Semi-Anthracite.			
Arkansas No. 5.	Spadra bed.	85.18	89.34
Semi-Bituminous.			
West Virginia No. 12.	Pocahontas bed.	80.47	90.48
West Virginia No. 10.	Pocahontas bed.	80.15	90.70
Arkansas No. 1.	Huntington bed.	79.26	88.05
Arkansas No. 3.	Huntington bed.	79.21	89.43
West Virginia No. 6.	New River field.	76.94	88.70
Bituminous High Grade.			
West Virginia No. 8.	Kanawha field.	64.72	86.50
West Virginia No. 4.	Upper Freeport bed.	68.29	86.23
Alabama No. 1.	Warrior field.	62.59	84.10
Kentucky No. 1.	Eastern field.	60.06	83.62
West Virginia No. 2.	Pittsburg bed.	55.71	82.13
Illinois No. 3.	Marion County.	63.26	81.62
Indian Territory No. 1.	Henryetta bed.	58.36	81.43
Bituminous Low Grade.			
Indiana No. 1.	Sullivan County.	55.04	80.23
Indian Territory No. 3.	McAlester bed.	56.08	79.96
Kansas No. 2.	Weir-Pittsburg bed.	59.91	79.42
Iowa No. 1.	Wapello County.	59.42	78.95
New Mexico No. 2.	Gallup field.	52.07	78.06
Kansas No. 4.	Atchison field.	55.85	77.59
Illinois No. 1.	Belleville field.	51.35	77.52
Missouri No. 3.	Putnam County.	54.93	76.97
Indian Territory No. 5.	McAlester bed.	54.08	76.47
Black Lignites.			
Colorado No. 1.	Boulder field.	53.69	76.15
Iowa No. 3 (coal)	Polk County.	48.77	75.82
Montana No. 1.	Red Lodge.	53.97	75.77
Brown Lignites.			
Wyoming No. 2.	Cambria field.	49.86	73.71
Texas No. 2.	Wood County.	50.43	72.06
North Dakota No. 2.	Williston field.	51.56	72.02