

DEPARTMENT OF THE INTERIOR  
UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

---

BULLETIN 382

---

THE EFFECT OF OXYGEN IN  
COAL

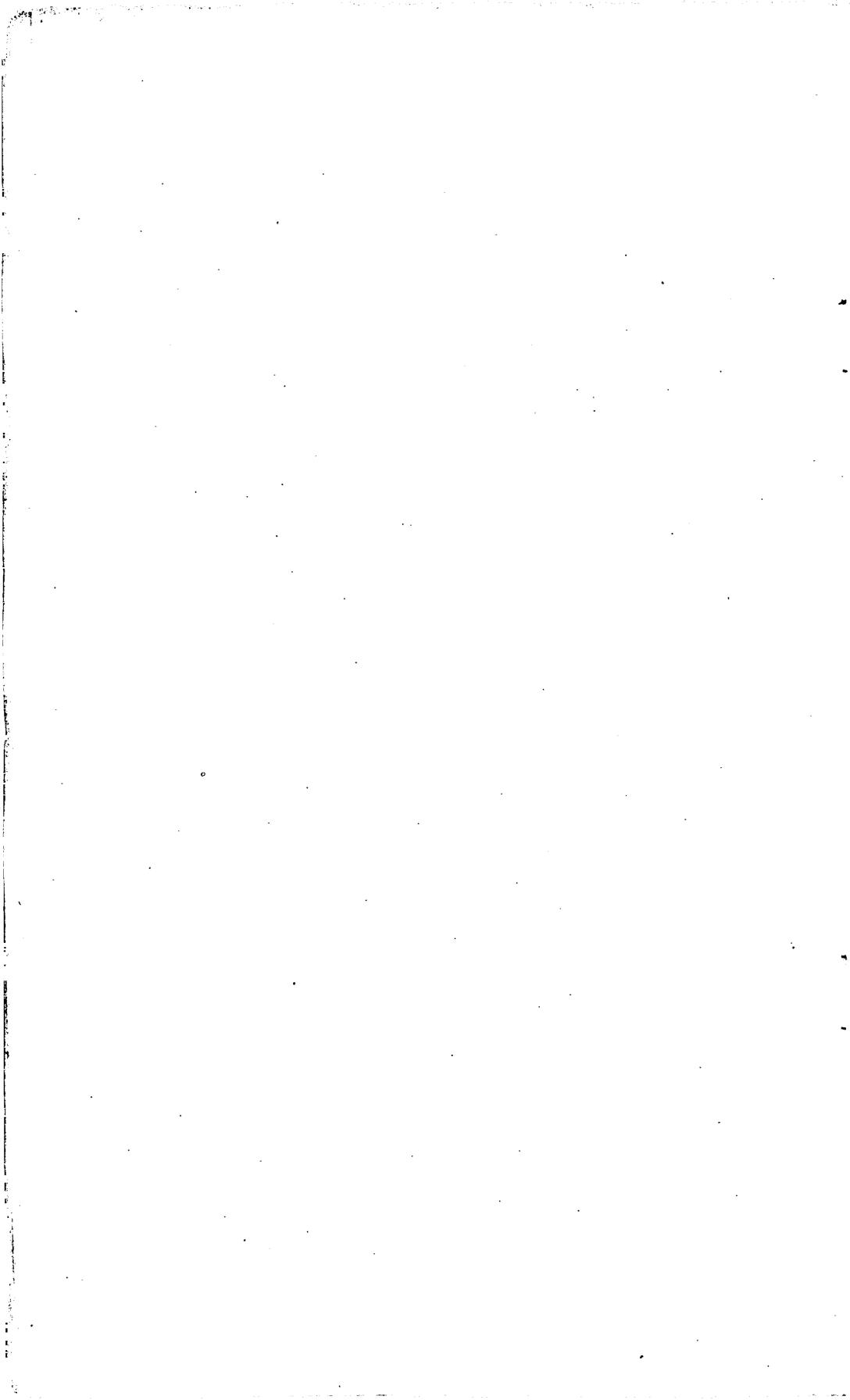
BY

DAVID WHITE



WASHINGTON  
GOVERNMENT PRINTING OFFICE

1909



## CONTENTS.

	Page.
Introduction.....	5
Deoxygenation in the formation of coal.....	6
Initial controlling factors.....	6
Stages of formation.....	6
Deoxygenation.....	7
Oxygen and ash as impurities.....	8
Evidence of their nearly equal value.....	8
Calorimeter tests.....	8
Ultimate analyses.....	9
Arrangement of analyses.....	19
Fuels high in oxygen or ash.....	19
Fuels of lower ash and oxygen.....	20
Relation to calorific value.....	21
Curve plotted from C : (O+ash) ratios and efficiencies.....	22
Determination of curve.....	22
Detailed study of a curve segment.....	22
Variations from the curve.....	23
Comparison with calculated thermal units.....	24
Forecast of fuel efficiency from ratios.....	24
Relations in moisture-free coals.....	25
Recalculation of analyses.....	25
Compensated calorific values.....	34
Value of moisture-free data.....	35
Relative negative value of ash and oxygen.....	36
Relative effect of the oxygen of moisture.....	37
Estimate of the empirical anticalorific value of oxygen.....	39
Negative value of oxygen and ash.....	39
Application of the curve.....	39
Fluctuation in effects of changes.....	40
Estimate applied to the analyses.....	40
Causes of variance from the curve.....	41
General statement.....	41
Causes not shown by ultimate analyses.....	41
Causes recognizable in analyses.....	42
Varying available hydrogen.....	43
Sulphur.....	44
Nitrogen.....	46
Anthracitization.....	46
Weathering.....	48
Quantitative relation of oxygen to coking.....	48
Supposed algal ingredients in coals.....	48
Source and chemical effects.....	48
Characteristics of algal coals.....	50
Possible connection with coking quality.....	50

	Page.
Quantitative relation of oxygen to coking—Continued.	
Hydrogen-oxygen ratios of coking coals.....	51
Description of diagram in Plate III.....	51
Indications of ratio limits.....	52
Application to algal hypothesis.....	53
Coking of high fixed carbon coals.....	53
Volatile-carbon ratios.....	53
Consultation of efficiency errors.....	54
Hydrogen and oxygen losses in the progressive development of coal.....	54
Available hydrogen as index of coking coals.....	55
Hydrogen-oxygen ratio the best index.....	56
Status of algal hypothesis.....	56
Mixture of coals for coking.....	57
General observations on the tabulated coals.....	58
Range of the samples.....	58
Rank of peats and lignites.....	58
Explanation of high oxygen.....	59
Quantitative relation of volatile carbon and hydrogen.....	59
Loss of volatile matter.....	60
Relation of stage of coal formation to classification.....	60
Like analyses for coals of different origin.....	60
Distinct categories impossible.....	61
Comparison of types.....	61
Obliteration of distinctions as a result of regional metamorphism.....	62
Oxygenation and weathering of coals.....	63
Changes in low-grade coals.....	63
Efficiency losses in weathering.....	63
Losses shown by analyses and ratio-efficiency curve.....	64
Losses shown by H : O and VC : C ratios.....	65
Underground weathering.....	67
Losses by weathering in shipment.....	69
Summary.....	70
Partial bibliography.....	73
Index.....	75

---

## ILLUSTRATIONS.

---

	Page.
PLATE I. Ratio-efficiency curve of coals tabulated.....	22
II. Segment of ratio-efficiency curve.....	22
III. Diagram showing hydrogen-oxygen ratios of coals.....	52

# THE EFFECT OF OXYGEN IN COAL.

---

By DAVID WHITE.

---

## INTRODUCTION.

This paper is the result of a comparative study of ultimate coal analyses made and published by the United States Geological Survey. This study, at first casually undertaken to devise an acceptable classification of coals based on chemical analyses, was continued in connection with a microscopic examination of a number of the coals. The initial comparisons, made from a relatively small number of analyses, not only confirmed a previous conviction that the elimination of oxygen incident to the development of a coal is economically far more important than has been generally suspected, but also showed that oxygen is very nearly as harmful as ash in coal.

The immediate purposes of the present study were: (*a*) To determine more definitely, from a comparative examination of a large number of ultimate analyses, the relative importance of oxygen as an impurity in various coals; (*b*) to illustrate the transition between various grades of coal of similar origin—transition mainly due to progressive devolatilization, brought about more or less directly by dynamic influences; (*c*) to ascertain the relative proportions of oxygen, hydrogen, and carbon in coking coals, especially with reference to a theory tentatively framed to explain the coking quality; and (*d*) to forecast the probabilities of successfully treating a large number of coals so as to render them amenable, in a softened condition, to satisfactory study under the microscope.

Although the hypothesis as to coking quality finds but partial support in the chemical analyses, its consideration has led to a method of predicting from an analysis with a fair degree of certainty whether any given coal will coke by the ordinary process. The unbroken transition between coals originally similar but now classed in widely different groups, whether of the same age or of different ages, as a result of dynamochemical action, appears demonstrated by the analyses as well as by field observation. This subject will not be

specially discussed in this paper, though the tables offer forcible, if not convincing, evidence concerning it.

The great number of ultimate analyses published by the Survey, covering samples of coals of so many sorts collected throughout the wide range of American coal fields, furnishes an unrivaled wealth of analytical data concerning the fuels of the country; and the fact that all are made under one highly expert direction, and are standardized, renders them especially valuable for comparative study.

The discussion of chemical changes that have occurred in the coals and of the nature of the compounds now existing in them is left to the professional chemist, who is familiar with the great mass of literature concerning the chemistry of coals.

Acknowledgments are gratefully tendered to Messrs. M. R. Campbell and J. S. Burrows for placing at my disposal many of their recalculations of the analyses from the "as received" to the "air-dried" basis and thus greatly lightening the labors of computation; also to Mr. Burrows for annotations as to the coking qualities of the coals. Thanks are also due to Mr. Wirt Tassin, of the National Museum, for frequent and generous gifts of information and counsel.

## DEOXYGENATION IN THE FORMATION OF COAL.

### INITIAL CONTROLLING FACTORS.

The great variation in kinds and qualities of coal is due to differences, many of them of wide range, in the consecutive influence or operation of three controlling and indispensable factors; that is, to differences (1) in the kinds and sources of the original ingredient matter; (2) in the conditions of accumulation and deposition of this matter; and (3) in the phase and stage of progress of the coal-forming process—the transformation of the organic matter into coals of various grades. The comparative importance of each of these cooperative and mutually related factors varies from coal to coal, and it is necessary to bear in mind that they combine not only in complex but also in constantly changing phases and efficiencies, so that their products, though often similar, are never exactly the same. It is to the third of these factors that the following discussion for the most part relates.

### STAGES OF FORMATION.

When the organic matter, chiefly of various vegetal types, accumulates under conditions favorable for the formation of coal, the process of conversion goes forward. In the ordinary course of events this process embraces two fundamentally important stages:

1. The putrefaction or fermentation stage, in which the action is essentially biochemical.

2. The stage of chemical and physical alteration, which is mainly induced and controlled by dynamic geologic influences, and in which the action may therefore, in contrast, be termed dynamochemical.

These two stages are practically consecutive, though slightly overlapping; and, on account of conditions that will readily be conceived and need not be discussed here,<sup>a</sup> the intensity and extent of the operation or progress of each stage varies greatly. The physical characters and qualities of the younger and less mature coals, including lignites and peats, are largely determined by the relative progress of the biochemical action, the most evident visible effect of which is the disintegration of the organic structures, usually accompanied by darkening of the color. On the other hand, the further progressive devolatilization, as well as the lithification, dehydration, and metamorphism of the coals, characterize the dynamochemical stage. The biochemical action, essentially the work of anaerobic bacteria, is, geologically speaking, relatively soon terminated, even when it progresses to a point just short of complete destruction of the original organism; the succeeding work, under the influence of geodynamic agencies, is still in progress, the ultimate goal being the practically complete devolatilization of the coal and its transformation into graphite.

#### DEOXYGENATION.

In all the chemical changes marking both stages in the conversion of organic débris into coal, the preeminently important result to man is elimination of oxygen. Economically this is the most essential incident of the process. From a beginning with over 40 per cent of oxygen, in the cellulose and lignose of the woody matter, which comprises so great a part of the organic substance actually entering into coal formation, to the present nearly devolatilized state of an anthracite, with less than 2.5 per cent of oxygen, deoxygenation has progressed continuously, though at varying rates, in every unweathered coal. As the original oxygen is more and more nearly eliminated, the heat efficiency of the coal increases. In other words, with respect to their efficiency as fuels, oxygen is an original impurity in coals, which improve according to the extent of its removal. It will be shown later that the deleterious effect of oxygen in coals greatly exceeds the common conception of it, being nearly equal to that of the same weight in ash. The negative importance of oxygen seems to be little realized outside of the ranks of coal analysts.

---

<sup>a</sup> See *Econ. Geology*, vol. 3, 1908, p. 292.

## OXYGEN AND ASH AS IMPURITIES.

## EVIDENCE OF THEIR NEARLY EQUAL VALUE.

## CALORIMETER TESTS.

At a conference held in Washington, March, 1907, for the purpose of discussing the classification of coals, I urged that a classification based on chemical composition, to be satisfactory for either technical or practical purposes, should give careful heed to the oxygen content, for the degree of deoxygenation would be found to be most intimately connected with the relative efficiency of the fuels. By using the limited number of ultimate analyses then made public by the fuel-testing plant of the United States Geological Survey as a basis of illustration, it was shown that, among coals of equal ash, the ascertained calorific values of the air-dried samples corresponded closely to the order of the ratios of the total carbon to the oxygen (C : O). The number of ultimate analyses showing approximately equal ash was, however, so small as to be inconclusive. I therefore attempted, by means of a critical comparison of all the analyses, to discover a coefficient for use in compensating for the highly variable ash content. From this study it was noted that, in general, so far as shown in the calorimeter, the deleterious effects of oxygen and of ash in the coals represented in the list were practically of very nearly equal importance. For example, the calorimeter tests seemed to show that two coals having the same carbon content, but with reverse proportions of ash and oxygen (one with 15 per cent ash and 4 per cent oxygen and the other with 4 per cent ash and 15 per cent oxygen) have nearly the same heat efficiency. In other words, oxygen and ash appear to be of nearly equal negative or anticalorific values.

The fact having been noted that the coals with constant ash arrange themselves as to efficiency largely in the order of the ratios of carbon to oxygen, it, at once became evident, oxygen and ash being of equal negative calorific effect, (1) that coals with constant oxygen should also similarly rank not far from the order of their carbon-ash ratios; and (2) that the efficiencies of coals in which both oxygen and ash vary should correspond nearly equally well to the relative order of the ratios of the carbon to oxygen plus ash. Examination of a more extended series of analyses confirms the conclusions based on the original list.

In these comparative studies the contribution of the hydrogen of the coal to the heat value is assumed to be nearly constant; hence the hydrogen is ignored temporarily, as also are the sulphur and the nitrogen. The main purpose is to show that in a miscellaneous series of coals of all grades those with high oxygen content will, in general, have approximately the same calorific value as those with

equally high ash if the C: (O + ash) ratios are the same; or, in other words, that, taking coals as they run, oxygen and ash are, according to the calorimetric tests, to be regarded as equally undesirable.

#### ULTIMATE ANALYSES.

To illustrate somewhat graphically the approximate equality of the anticalorific values of these two great impurities in coal, while at the same time showing the relatively close correspondence of the calorific values to the sequence of the ratios C: (O + ash), Table 1 (pp. 11-18) has been compiled showing a series of over 300 ultimate analyses of air-dried samples of fuels. All these analyses were made in the laboratories of the United States Geological Survey.

As first compiled the table included all the ultimate coal analyses which, in December, 1907, had come to hand. By mere coincidence they numbered 250. Nearly 70 additional analyses of samples by the geologists working in the various coal areas have since been intercalated. These intercalations, many of which represent weathered material, have alphabetic designations affixed to the numbers, thus retaining the original series of numbers for the mined coals especially investigated by the Survey.

The air-dried coal samples, according to the later practice of the chemical laboratory, are those that, after pulverization, were dried in a special oven in a gentle current of air 10° to 20° above the temperature of the laboratory.<sup>a</sup> In the earlier laboratory work the samples were crushed fine, spread out on shallow trays, and dried in the air of the laboratory for twenty-four to ninety-six hours, or until the loss between two successive weighings (made twelve to twenty-four hours apart) was small, usually less than 1 per cent.<sup>b</sup>

All but one of the analyses will be found in Professional Paper 48, or in Bulletins 260, 261, 290, 316, or 332 of the United States Geological Survey. Most of the recalculations of the analyses and computations of ratios in this paper were done without the aid of the computing machine and are subject to correction. For original forms, including "as received" and "dry coal" recalculations, the reader is referred to the papers here mentioned.

It will be observed that the coals here listed represent most of the American coal fields. They come from 27 States and Territories. One is from Batan Island and one from Mexico. In age they range from basal Mississippian (Pocono) to Recent. The post-Paleozoic coals belong to the Kootenai (basal Cretaceous); Benton, Eagle, Mesaverde, and Laramie (Upper Cretaceous); "Upper Laramie," Fort Union, Bridger, and Gulf Coast Eocene; Pacific Coast Miocene;

<sup>a</sup> For description of this process see Bull. U. S. Geol. Survey No. 290, 1906, pp. 29-30.

<sup>b</sup> See Prof. Paper U. S. Geol. Survey No. 48, 1906, p. 177. For comparison of results see Bull. U. S. Geol. Survey No. 323, p. 8.

and Atlantic Coast post-Pleistocene. In kinds they embrace peats and xyloid and earthy lignites (brown coals), as well as subbituminous, bituminous (dry and coking), semibituminous, semianthracite, anthracite, and graphitic coals. In order not to omit any ultimate analysis of a coal investigated by the Survey, so far as they had come to hand up to the close of 1907, the semigraphite from Providence is also included. The graphitization of this highly metamorphic Carboniferous coal is so nearly complete that, although a coal from the genetic standpoint, it can not be regarded as a fuel, for it is practically incombustible unless chemically treated. It is used mainly for foundry facing. The lower-class coals are distinguished in accordance with the simple and very practical system recently proposed by M. R. Campbell.<sup>a</sup> This classification, based on weathering and salient physical characters, is briefly as follows:

Bituminous coals, except cannel and block (which are recognized by special well-known criteria), are more thoroughly jointed, and in weathering split generally in agreement with preexisting cleavage, the particles remaining prismatic even when very minute.

Subbituminous coals are black, generally less jointed, and have poor cleavage, which shows only in the larger blocks. On exposure to the atmosphere the lumps check irregularly, the resultant fragments, however small, being irregular in outline and having rough faces instead of cleavage planes. Weathering is characterized (very conspicuously in the longer exposed fragments) by separation of the coal in plates parallel to the bedding, this process continuing to invisible limits.

Lignites are distinguished from subbituminous coals only by their brown, instead of black, color and generally woody aspect. They are the "brown coals."

The higher grade coals are provisionally grouped as proposed by Prof. F. F. Grout.<sup>b</sup>

It will be noted that the samples analyzed are not always marketable coal; in many cases they represent fine coal, screenings, refuse, slack, dust (culm), waste and "bone." The low position of a number of the high-grade coals—for example, No. 30 (W. Va. 24) from the famous Pocahontas bed—is accounted for by the great amount of ash in the bony layer from which the sample was taken.

<sup>a</sup> Econ. Geology, vol. 3, 1908, p. 134.

<sup>b</sup> Op. cit., vol. 2, 1907, p. 240.

TABLE 1.—Ultimate analyses of 319 American coals, "air-dried" basis, from the chemical laboratory of the U. S. Geological Survey, with calorific value and C: (O+ash) ratio of each coal.

No.	Designation of coal.	Locality.	Kind.	N.	S.	H.	C.	O.	Ash.	C O+ash.	Calo- ries.	Mois- ture.	Fixed car- bon.	Vola- tile mat- ter.	Age.	Formation.	Remarks.
1	Mass. 1.	Halifax.	P.	1.40	0.58	5.55	40.78	30.95	20.74	0.79	4,055	13.60	18.72	46.94	Recent.	Fort Union.	Car sample.
2	N. Dak. 1B.	Lehigh.	L.	.55	3.95	5.57	44.11	33.07	12.75	1.06	4,321	29.85	32.58	32.58	Tertiary.	Fort Union.	Country bank.
2a	Mont. 3701.	Near Miles.	L.	.65	.66	4.51	48.10	28.17	18.00	1.04	4,432	15.12	36.54	30.34	do.	do.	Prospect.
3	Wyo. 3694.	Labarge Range.	S.	.85	6.1	4.45	48.65	35.57	6.87	1.07	4,468	10.88	40.15	39.15	Creaceous.	Montana.	Mine; car sample.
3b	N. Dak. 3.	Wilton.	L.	.39	1.32	5.88	47.45	35.08	8.88	1.08	4,498	26.64	27.92	36.54	Tertiary.	Fort Union.	Oil rock.
4	Ark. 10.	Near	L.	.91	1.65	5.60	48.51	31.36	12.97	1.09	4,714	19.13	32.54	35.36	do.	Fort Union.	Country bank.
4a	Mont. 3816.	Near Glendive.	L.	.65	5.63	48.55	34.21	9.41	1.11	1.11	4,522	24.11	15.80	50.68	Tertiary.	Fort Union.	Car sample.
5	N. Dak. 2B.	Williston.	L.	.88	7.1	5.66	40.19	33.86	6.10	1.21	4,922	22.77	35.72	34.41	do.	do.	Briquetted.
6	Tex. 1.	Orlando.	P.	2.56	4.49	6.06	51.18	34.03	5.68	1.28	4,961	13.70	24.30	56.83	Recent.	Fort Union.	Mine; car sample.
7	Tex. 1.	Crockett.	L.	.71	2.02	5.57	52.06	25.53	14.85	1.29	5,199	13.40	29.00	42.75	Tertiary.	Fort Union.	Do.
8	Wyo. 3.	Aladdin.	L.	.72	6.86	5.03	49.59	20.60	17.20	1.31	5,034	15.42	33.61	38.73	Tertiary.	Montana.	Do.
9a	Wyo. 3892.	Fall River.	S.	.72	2.85	4.70	52.38	23.72	14.84	1.29	5,106	10.32	30.48	43.46	Creaceous.	Evanson.	Surface sample.
10	Cal. 1.	Lehigh.	B.	1.22	4.06	4.18	52.39	12.40	25.75	1.37	5,106	10.32	30.48	43.46	Carboniferous.	"Coal Meas."	Slack.
11	Cal. 1.	Norrieger.	B.	.73	3.40	3.92	53.55	10.48	27.57	1.41	5,201	5.74	37.05	31.49	Tertiary.	"Coal Meas."	Mine; car sample.
12	W. Yo. 2326.	Winnac County.	B.	.88	4.78	3.95	53.55	10.48	27.57	1.41	5,399	9.05	34.23	31.17	Carboniferous.	Evanson.	Slack.
13	N. Dak. 2.	Winnac County.	B.	.91	6.3	5.61	55.16	30.98	6.71	1.42	5,251	7.21	36.95	37.96	Tert.-Cret.?	Fort Union.	Small mine.
14	Ill. 2.	O'Fallon.	L.	.78	4.30	4.57	54.06	12.13	24.16	1.40	5,471	16.73	39.49	37.10	Tertiary.	Fort Union.	Mine; car sample.
15	Mo. 3.	Norrieger.	B.	.92	3.46	4.65	54.30	14.23	22.35	1.48	5,471	5.31	39.24	34.29	Carboniferous.	"Coal Meas."	Slack.
16	Mo. 3.	Norrieger.	B.	.92	3.46	4.65	54.30	14.23	22.35	1.48	5,471	5.31	39.24	34.29	Carboniferous.	"Coal Meas."	Slack.
17	N. Mex. 2.	Gallop.	B.	.98	1.30	5.09	55.16	19.74	23.90	1.50	5,508	5.31	39.12	32.12	do.	do.	Slack.
18	Wyo. 2.	Chambla.	B.	.90	4.77	4.54	57.84	17.52	22.56	1.57	5,498	2.73	37.83	34.81	do.	do.	Mine; car sample.
19	Tex. 2.	Hoyt.	B.	1.36	4.22	4.87	57.84	17.52	22.56	1.62	5,812	10.66	40.11	39.49	do.	do.	Mine; car sample.
20	Mexico 2B.	Cambla.	B.	1.02	4.06	3.96	58.97	16.72	20.37	1.69	5,812	10.66	40.11	39.49	do.	do.	Mine; car sample.
21	Mexico 2B.	Cambla.	B.	1.02	4.06	3.96	58.97	16.72	20.37	1.69	5,812	10.66	40.11	39.49	do.	do.	Mine; car sample.
22	Tex. 4.	Hoyt.	B.	.97	4.78	4.06	58.83	19.48	9.96	1.71	5,859	9.76	47.97	37.51	Carboniferous.	"Coal Meas."	Mine; car sample.
23	Tex. 4.	Hoyt.	B.	.97	4.78	4.06	58.83	19.48	9.96	1.71	5,859	9.76	47.97	37.51	Carboniferous.	"Coal Meas."	Mine; car sample.
24	Tex. 3.	Olean.	L.	1.18	1.30	5.13	58.43	23.66	10.30	1.72	5,715	17.69	43.65	36.17	do.	Fort Union.	Do.
25	Wyo. 1.	Monarch.	B.	1.09	1.63	4.97	59.61	28.99	4.70	1.72	5,715	17.69	43.65	36.17	Tertiary.	Fort Union.	Do.
25a	Mont. 3512.	Reft district.	B.	.65	4.73	4.77	59.61	15.19	18.63	1.78	5,824	4.50	38.16	26.15	Carboniferous.	Kootenai.	Mine sample.
26	Ill. 7A.	Collinsville.	B.	.90	1.63	4.73	57.43	14.00	18.22	1.78	5,863	6.80	38.16	26.15	Carboniferous.	"Coal Meas."	Slack.
27	Tenn. 11.	Ozone.	B.	1.13	9.2	3.96	60.52	4.90	22.82	1.81	5,893	2.17	48.97	21.34	do.	Pottsville.	Do.
28	Mo. 7B.	Norrieger.	B.	1.02	4.13	4.23	57.82	8.98	22.57	1.81	5,893	2.17	48.97	21.34	do.	do.	Nut coal.
28a	Mont. 3856.	Near Thompson's.	B.	1.35	6.0	4.76	60.49	13.23	19.47	1.85	6,029	4.14	43.75	32.64	Carboniferous.	Mesaverde.	Small mine.
29	Colo. 2.	Prombush.	B.	1.14	6.2	4.65	60.97	16.20	15.92	1.87	5,929	5.39	46.03	32.66	do.	Eagle.	Mine; car sample.
30	W. Va. 24.	Gary.	Sb.	.66	.55	3.33	62.36	3.97	28.77	1.93	6,002	9.05	43.03	36.70	Carboniferous.	Pottsville.	"Bony" layer.
31	Mont. 1.	Red Lodge.	S.	1.36	7.6	5.25	60.41	20.00	11.22	1.93	5,989	9.05	43.03	36.70	Tertiary.	Fort Union.	Mine; car sample.
31a	Colo. 3729.	Carbonera.	B.	1.30	.50	5.37	61.17	16.58	15.08	1.93	6,089	6.76	44.45	33.71	Carboniferous.	Mesaverde.	Mine sample.

<sup>b</sup> From shallow mine or country bank.

<sup>a</sup> Coals more or less weathered.

TABLE 1.—Ultimate analyses of 319 American coals, "air-dried" basis, from the chemical laboratory of the U. S. Geological Survey, with calorific value and C: (O+ash) ratio of each coal—Continued.

No.	Designation of coal.	Locality.	Kind.	N.	S.	H.	C.	O.	Ash.	C O+ash	Calo- ries.	Mois- ture.	Fixed car- bon.	Vola- tile mat- ter.	Age.	Formation.	Remarks.
32	Colo. 1.	Lafayette.	S.	1.22	5.58	5.75	61.13	24.95	6.32	1.95	5,995	13.49	43.03	37.11	Cretaceous	Laramie.	Mine; car sample.
33	Ill. 24A.	Livingston.	B.	1.97	4.56	4.70	59.37	12.88	17.51	1.95	6,068	4.92	43.89	33.63	Carboniferous	"Coal Meas."	Screenings.
33a	N. Mex. 3811.	West of Putnam.	S.	1.51	5.90	6.30	62.20	16.01	10.14	1.96	5,994	8.86	43.13	37.87	Cretaceous	Mesa Verde.	Little depth.
34	Ind. 20.	Brazil.	B.	1.16	2.17	3.69	60.96	11.09	19.99	1.97	6,089	4.38	44.73	30.90	Carboniferous	"Coal Meas."	Screenings.
35	Ark. 9.	Bonanza.	Sb.	1.28	2.04	3.59	62.49	5.70	25.90	1.97	6,067	1.11	57.64	15.35	do.	do.	Slaek.
36	Mont. 3.	Chariton.	S.	3.42	5.56	5.95	59.89	16.57	13.55	1.98	6,105	9.22	44.52	32.71	do.	do.	Run of mine.
37	Iowa 5.	Bridger.	S.	1.09	4.67	6.32	17.34	13.82	15.80	2.00	6,126	5.63	47.15	33.40	Cretaceous	Eagle.	Mine; car sample.
38	Ill. 27.	Auburn.	B.	1.01	4.50	4.93	59.88	14.38	15.30	2.01	6,135	6.67	42.02	36.01	Carboniferous	"Coal Meas."	Run of mine.
39	Ill. 4.	Troy.	B.	1.17	3.33	61.79	18.32	11.55	12.91	2.03	6,106	11.40	44.30	32.45	do.	do.	Lump.
39a	Wyo. 3699.	Labarge Range.	S.	1.09	1.14	5.39	62.05	24.56	5.77	2.04	6,039	9.02	47.55	35.59	Cretaceous	Montana.	Coal drift.
39b	Wyo. 3780.	Northeast of Hanna.	S.	1.73	2.41	5.73	60.53	23.55	6.05	2.04	6,040	10.12	48.13	36.70	(?)	"Upper Laramie."	Exposed.
40	Ind. 3.	Boonville.	B.	1.18	5.24	4.83	59.58	12.09	17.08	2.04	6,090	5.12	42.92	34.88	Carboniferous	"Coal Meas."	Small size.
41	Wyo. 4.	Hanna.	S.	.90	2.29	5.42	62.68	23.23	7.48	2.04	6,116	9.21	42.04	45.27	Tertiary	Fort Union.	Mine; car sample.
42	Ill. 8.	Paisley.	B.	1.08	4.68	5.25	59.88	16.01	13.10	2.06	6,110	9.21	41.78	35.31	Carboniferous	"Coal Meas."	do.
43	Mo. 1.	Sprague.	B.	.99	5.53	4.64	60.00	8.46	20.38	2.08	6,191	3.50	40.77	35.35	do.	do.	do.
44	Ill. 6.	Coffeen.	B.	1.23	4.45	4.88	60.51	14.20	14.73	2.09	6,199	5.13	47.46	32.68	do.	do.	Run of mine.
44a	Wyo. 3693.	Labarge Range.	S.	1.03	2.10	5.74	61.76	25.96	3.41	2.10	6,037	10.78	43.94	40.46	Cretaceous	Montana.	Prospect.
44b	Mont. 3515.	Belt district.	S.	.69	3.80	4.02	62.51	9.16	19.82	2.11	6,094	1.93	51.44	26.81	do.	Kootenai.	Country bank.
45	Ill. 23A.	Donkville.	B.	1.04	4.58	4.55	60.93	10.94	17.96	2.11	6,180	2.86	43.14	36.04	Carboniferous	"Coal Meas."	Lump.
46	Wash. 1.	Renton.	S.	1.30	.68	4.91	63.28	16.92	12.91	2.12	6,182	5.98	45.96	35.15	Eocene	do.	Pea coal; car sample.
46a	Colo. 4050.	Near Glenwood Springs.	B.	1.58	.98	5.04	62.74	19.71	9.95	2.12	6,226	7.05	47.60	35.40	Cretaceous	Mesa Verde.	Mine sample.
47	Ill. 21B.	Troy.	B.	1.24	1.17	5.14	62.84	17.26	12.35	2.12	6,278	8.52	46.95	32.18	Carboniferous	"Coal Meas."	Run of mine.
48	Iowa 2.	Hamilton.	B.	1.46	5.20	4.84	60.36	11.15	16.99	2.14	6,212	4.25	41.75	37.02	do.	do.	do.
49	Ill. 7B.	Collinsville.	B.	1.03	4.69	5.14	60.71	14.77	13.66	2.14	6,229	7.60	41.19	37.55	do.	do.	do.
50	Wash. 1B.	Renton.	S.	1.29	.80	5.16	63.35	16.82	12.58	2.15	6,273	5.20	45.68	36.54	Eocene	do.	Run of mine; car sample.
51	Ind. 1.	Milfred.	B.	1.22	2.58	5.20	62.20	14.99	13.81	2.16	6,336	8.66	42.67	39.86	Carboniferous	"Coal Meas."	Run of mine.
51a	Philipp.	Batan Island.	S.	1.33	1.36	5.55	62.91	23.29	5.56	2.17	6,101	7.06	43.44	33.94	Miocene?	do.	Probably oxidized.
52	Iowa 4.	Centerville.	B.	.94	4.46	5.31	61.25	16.56	11.48	2.18	6,237	10.03	41.22	37.27	Carboniferous	"Coal Meas."	Lump.
52a	N. Mex. 3952.	Near Blackrock.	B.	1.03	1.54	4.97	63.00	12.36	16.62	2.18	6,500	4.01	40.22	39.12	Cretaceous	Mancos.	Mine sample (?).
52b	Wyo. 2325.	Almy.	S.	1.23	2.42	4.64	64.28	21.56	7.73	2.19	6,220	7.73	44.52	39.45	Tert.-Cret.?	Evanson.	Mine.
52c	Colo. 3463.	Lay.	B.	1.16	1.05	5.00	63.43	23.37	6.49	2.19	6,198	9.87	46.97	36.67	Cretaceous	Mesa Verde.	Prospect.
53	Ill. 25B.	Germanatown.	B.	1.12	5.05	6.00	66.98	13.57	14.24	2.19	6,337	5.79	43.18	37.79	Carboniferous	"Coal Meas."	Lump.
53a	Wyo. 3917.	Near Fort Steele.	S.	1.56	.85	5.16	63.57	25.05	3.80	2.20	6,310	8.70	48.44	39.05	Cretaceous	Lewis.	Shaft.
54	Ill. 9C.	Stanton.	B.	.95	4.39	4.41	62.23	10.41	17.71	2.21	6,273	2.25	47.09	32.95	Carboniferous	"Coal Meas."	Coal drift.
55	Ill. 22A.	Maryville.	B.	1.06	5.68	4.83	60.94	13.66	13.83	2.21	6,267	6.39	41.89	37.89	do.	do.	Lump.
55a	Wyo. 3698.	Labarge Range.	S.	1.08	.84	5.68	63.81	25.75	2.84	2.23	6,258	10.22	45.98	39.47	Cretaceous	Montana.	Drift.

56	Wyo. 4B	Hanna	88	6.18	64.01	21.62	7.04	2.23	6.183	8.94	42.70	41.32	Tertiary	Fort Union	Mine; car sample.
57	Ill. 29B	Livingson	85	5.11	64.07	14.62	13.05	2.23	6.302	7.14	44.09	35.73	Carboniferous	"Coal Meas."	Run of mine.
57a	Wyo. 3605	Hanna	1.29	5.41	64.07	21.58	7.14	2.23	6.420	8.07	47.87	41.93	Tertiary	Fort Union	Top bench No. 1; mine sample.
58	Ill. 6B	Coffeen	1.10	4.67	61.96	12.15	15.43	2.24	6.229	4.17	47.77	32.63	Carboniferous	"Coal Meas."	Run of mine.
59	Ill. 29	Livingson	1.08	4.71	61.67	10.97	13.55	2.24	6.393	5.58	45.14	35.73	do.	do.	Lump.
60	Lowva 1	Laddsdale	1.97	5.20	61.80	10.90	16.52	2.25	6.329	5.21	46.51	31.76	do.	do.	Screened.
61	Ill. 1	O'Fallon	1.09	4.25	5.99	62.01	13.82	2.25	6.260	6.28	41.08	38.92	do.	do.	Coarse coal.
62	Ill. 15	Centralia	1.07	4.04	4.99	62.01	13.82	2.25	6.356	6.00	43.91	36.28	do.	do.	From prospect.
62a	Utah 4013	Near Sunnyside	1.30	4.47	64.88	20.11	8.53	2.26	6.293	5.12	53.21	33.14	Cretaceous	Mesaverde	Lump.
63	Lowva 3	Altoona	1.93	6.83	4.93	60.62	11.16	2.27	6.309	4.52	38.99	40.96	Carboniferous	"Coal Meas."	Mine; car sample.
64	N. Mex. 1	Gallop	1.05	5.03	64.34	21.14	7.10	2.28	6.353	10.86	46.90	35.14	Carboniferous	"Coal Meas."	Run of mine.
65	Kans. 2B	Yale	1.11	5.34	4.26	62.65	13.13	2.32	6.329	1.51	48.42	28.25	do.	do.	Do.
66a	Ind. 14	Seelyville	1.26	5.76	4.99	62.05	11.90	2.33	6.430	4.34	42.64	38.20	Cretaceous	Mesaverde	Mine sample.
66b	Colo. 3498	Meeker	1.11	5.34	62.05	20.41	7.42	2.33	6.414	7.62	42.64	38.20	Carboniferous	"Coal Meas."	Run of mine.
67	Ind. 13	Star Haute	1.87	3.37	5.25	63.39	14.31	2.34	6.414	3.58	47.41	32.95	do.	do.	Sampled.
68	Ind. 4	Terr City	1.24	2.59	4.66	64.10	11.36	2.34	6.414	3.58	47.41	32.95	do.	do.	Coal No. 6.
69	Ill. 30	Shioh station	1.03	4.80	4.92	62.60	12.20	2.35	6.514	5.74	47.17	34.89	do.	do.	Lump.
70	Ill. 21	Troy	1.22	1.55	4.94	64.76	15.34	2.35	6.514	3.74	47.17	34.89	do.	do.	Lump.
71	Ill. 22B	Marville	1.00	4.90	4.82	63.21	13.25	2.36	6.372	2.06	44.81	36.77	do.	do.	Screenings.
72a	Colo. 3545	Lehigh	1.38	4.66	5.58	65.05	20.96	2.38	6.312	10.00	50.98	32.74	Cretaceous	Mesaverde	Lump.
73	Ill. 31	Book Cliffs district	1.47	4.05	4.83	63.47	11.84	2.38	6.394	3.77	45.94	35.62	do.	do.	Prospect.
73a	Colo. 3490	Worden	1.13	3.89	5.13	65.51	16.92	2.39	6.532	6.17	47.13	36.28	Carboniferous	"Coal Meas."	Screenings.
73b	Mont. 4115	Book Cliff field	1.92	2.43	4.33	65.17	12.66	2.40	6.348	3.70	52.68	29.13	do.	do.	Mine sample.
73c	Wyo. 2283	Stockett district	1.03	5.8	5.24	65.76	23.96	2.40	6.385	7.57	47.20	40.49	do.	do.	Do.
74	Ind. 2	Mammoth Holl.	1.25	4.60	5.11	62.97	12.56	2.41	6.410	6.24	42.76	37.49	do.	do.	Mine; shallow.
75	Ind. 17	Boonville	1.94	3.85	5.03	63.70	14.87	2.41	6.410	6.24	42.76	37.49	do.	do.	Run of mine.
75a	Colo. 3462	Bicknell	1.22	1.14	5.23	65.33	20.41	2.44	6.446	7.36	46.80	34.23	do.	do.	Do.
75b	Colo. 3704	Lay	1.40	5.4	5.24	66.12	21.92	2.44	6.419	8.66	47.29	37.68	Cretaceous	Mesaverde	Outcrop.
76	Ill. 14	Axial	1.19	4.52	5.00	63.85	12.64	2.48	6.534	8.91	49.22	37.09	do.	do.	Do.
77	Ohio 3	Springfield	1.28	1.88	5.05	65.62	12.80	2.50	6.496	5.13	44.31	37.70	Carboniferous	"Coal Meas."	Mine sample.
78	Ind. 12	Shawnee	1.14	3.61	4.05	65.62	14.12	2.51	6.519	6.24	46.68	35.03	do.	do.	Lump.
79	Kans. 2	Bush	1.14	3.61	4.05	65.62	14.12	2.51	6.519	6.24	46.68	35.03	do.	do.	Sample.
80	Ind. 6	Yale	1.94	4.63	4.56	63.14	6.69	2.54	6.600	2.23	47.63	31.87	do.	do.	Run of mine.
81	Ill. 9A	Hymera	1.19	4.63	5.15	64.22	11.50	2.59	6.555	5.91	42.71	38.07	do.	do.	Do.
81a	Ariz. 4112	Stanton	1.04	4.43	5.18	64.49	13.06	2.59	6.555	5.91	42.71	38.07	do.	do.	Do.
82	Ill. 26	Near St. Michaels	1.28	4.42	5.75	66.81	21.69	2.60	6.723	9.89	46.95	39.07	Cretaceous	Mesaverde	Do.
83	Wyo. 6	Lincoln	1.21	4.02	4.75	65.02	11.15	2.60	6.579	3.41	45.62	37.12	Carboniferous	"Coal Meas."	Run of mine; car sample.
84	Ill. 19E	Kenmerer	1.10	5.81	66.35	22.07	3.52	2.61	6.456	8.68	46.49	41.31	do.	do.	Do.
84a	Ill. 19E	Ziegler	1.53	5.4	4.54	67.48	14.99	2.61	6.625	5.27	52.58	31.23	Carboniferous	"Coal Meas."	Screened.
85	Ala. 2B	Carbal	1.12	6.0	5.20	67.42	22.64	2.62	6.654	8.67	49.99	38.32	do.	do.	Old drift sample.
86	N. Mex. 3A	Axial	1.52	1.14	4.46	67.35	10.69	2.63	6.660	2.29	51.64	31.23	Carboniferous	Mesaverde	Run of mine.
87	Ind. 16	Van Houten	1.13	4.50	4.83	67.84	8.742	2.64	6.742	1.48	48.80	32.71	do.	do.	Mine.
88	Kans. 6	Linton	1.25	4.00	5.02	64.82	12.04	2.63	6.623	4.68	44.24	38.59	Carboniferous	"Coal Meas."	Run of mine.
89	Tenn. 9B	Jewett	1.14	4.00	4.54	65.65	7.75	2.66	6.693	2.09	49.03	31.96	do.	do.	Lump.
90	Mo. 5	Coalmont	1.26	7.8	4.72	67.76	6.01	2.66	6.693	1.03	62.89	26.61	do.	do.	Slack.
91	Ind. 12	Higbee	1.02	5.68	4.69	64.52	8.72	2.67	6.688	1.71	44.95	37.47	do.	do.	Run of mine.
92	Ohio 2	Hartwell	1.25	4.13	5.01	65.28	11.88	2.68	6.688	4.45	45.68	37.42	do.	do.	Do.
92	Ohio 2	Superior	1.25	5.17	65.14	12.51	11.76	2.68	6.625	5.61	45.44	37.19	do.	do.	Do.

c Sample probably deteriorated.

d Coals more or less weathered.

e From shallow mine or country bank.

f Car sample.

TABLE 1.—Ultimate analyses of 319 American coals, "air-dried" basis, from the chemical laboratory of the U. S. Geological Survey, with calorific value and C: (O+ash) ratio of each coal—Continued.

No.	Designation of coal.	Locality.	Kind.	N.	S.	H.	C.	O.	Ash.	C O+ash	Calo- ries.	Mois- ture.	Fixed car- bon.	Vola- tile mat- ter.	Age.	Formation.	Remarks.
93	N. Mex. 3B.	Van Houten.	B.	1.22	8.6	4.60	68.00	8.91	16.41	2.68	6,823	1.40	48.98	33.21	Cretaceous.	Montana.	Mine.
94	Ill. 23B.	Donkville.	B.	1.03	4.93	4.91	65.10	10.95	13.03	2.71	6,598	2.23	45.93	38.81	Carboniferous.	"Coal Meas."	Slack.
95	Ill. 19C.	Ziegler.	B.	1.49	5.10	5.10	67.91	13.53	11.43	2.72	6,596	6.01	52.23	30.33	do.	do.	Run of mine.
96	Ill. 24A.	New Baden.	B.	1.10	5.33	4.94	64.86	12.20	11.57	2.72	6,575	4.36	47.43	36.64	do.	do.	Screenings.
97	Ill. 3.	Marion.	B.	1.43	1.77	4.92	67.30	12.99	11.59	2.74	6,724	5.96	52.16	30.29	do.	do.	Run of mine;
															No. 6.	do.	
98	Ind. 5.	Haymer.	B.	1.16	4.60	5.07	65.44	12.01	11.72	2.75	6,700	5.21	44.65	38.42	do.	do.	Run of mine.
99	Ill. 9B.	Stanton.	B.	1.09	4.40	5.14	65.57	11.57	11.48	2.75	6,717	4.03	44.18	40.31	do.	do.	Lump.
100	N. Mex. 3C.	Van Houten.	B.	1.20	6.5	4.70	68.66	9.00	15.74	2.77	6,855	1.37	49.23	33.66	Cretaceous.	Montana.	Mine.
101	Ind. 11.	Dugger.	B.	1.44	1.47	5.22	67.63	15.76	8.48	2.79	6,806	8.49	48.16	34.87	Carboniferous.	"Coal Meas."	Lump.
101a	Colo. 3550.	Book Cliffs field.	B.	1.26	6.63	5.19	68.46	13.25	11.21	2.79	6,757	4.30	47.53	33.32	Cretaceous.	Mesaverde.	Mine sample.
102	Ind. 9.	Maxville.	B.	1.12	3.56	5.19	66.48	12.46	11.20	2.81	6,714	5.24	45.73	37.83	Carboniferous.	"Coal Meas."	Lump.
103	Ind. 18B.	Winston.	B.	1.18	1.49	5.50	67.95	16.80	7.08	2.84	6,881	8.92	48.57	35.43	do.	do.	Do.
104	Ill. 34B.	Harrisburg.	B.	1.38	2.96	4.69	67.29	10.95	12.73	2.84	6,883	2.92	51.25	33.10	do.	do.	Run of mine.
105	Ohio 1.	Wellston.	B.	1.17	4.85	5.12	65.70	10.59	12.57	2.86	6,727	2.86	44.18	40.59	do.	do.	Do.
106	Ill. 19.	Ziegler.	B.	1.48	5.7	4.85	69.05	14.23	9.82	2.86	6,697	6.39	54.46	29.32	do.	do.	Do.
107	Ind. 9B.	Maxville.	B.	1.19	3.53	5.14	66.79	11.30	12.05	2.86	6,811	3.17	45.81	38.97	do.	do.	Sized coal.
108	Ky. 4.	Wheatcroft.	B.	1.28	4.67	4.53	66.50	8.43	14.59	2.88	6,830	2.54	46.79	36.08	do.	do.	Run of mine.
109	Ohio 9B.	Clarton.	B.	1.12	3.55	4.80	67.31	10.58	12.64	2.89	6,805	2.65	45.65	39.06	do.	do.	Do.
110	Ill. 10.	West Frankfort.	B.	1.46	1.56	4.88	68.56	11.25	12.29	2.89	6,866	2.79	50.57	34.35	do.	do.	Slack.
110a	Wyo. 3891.	McDougal's Moun- tain.	B.	1.38	3.33	5.31	69.07	18.99	4.92	2.89	6,879	6.50	48.42	39.95	Cretaceous.	Benton.	Prospect; new.
111	Ky. 3.	Barnsley.	B.	1.43	3.60	5.27	66.75	12.66	10.29	2.92	6,829	5.85	46.96	33.90	Carboniferous.	"Coal Meas."	Run of mine.
112	Ill. 12B.	Bush.	B.	1.02	4.80	68.30	11.74	11.54		2.92	6,756	3.97	51.43	33.06	do.	do.	Do.
112a	Wyo. 3509.	Fort Steele.	B.	1.79	8.8	5.17	68.93	17.24	5.99	2.96	6,782	2.92	49.76	38.53	Carboniferous.	Mesaverde.	Mine.
113	Mo. 6.	Huntsville.	B.	1.08	6.34	4.74	65.71	8.85	13.28	2.96	6,785	4.49	45.44	38.79	Carboniferous.	"Coal Meas."	Lump.
114	Ala. 2.	Carbon Hill.	B.	1.55	1.02	4.79	69.24	10.87	12.53	2.96	6,916	2.58	51.74	33.15	do.	Pottsville.	Sized.
115	Ind. T. 8.	(?)	B.	1.64	1.93	4.67	68.65	8.86	14.25	2.97	6,837	2.99	50.21	33.25	do.	"Coal Meas."	Car sample.
116	Ill. 12C.	Bush.	B.	1.19	2.65	4.83	68.36	11.02	11.95	2.97	6,862	3.22	51.70	33.03	do.	do.	Run of mine.
117	Ind. 8.	Terre Haute.	B.	1.13	3.90	5.21	67.17	11.47	11.12	2.97	6,848	5.19	45.76	37.93	do.	do.	Lump; deep coal.
118	N. Mex. 4B.	Brilliant.	B.	1.53	2.62	4.87	69.48	10.62	14.78	2.97	6,827	1.40	49.02	34.80	Cretaceous	Montana	Screenings.
119	Ill. 11B.	Carterville.	B.	1.37	4.88	68.25	10.50	12.38		2.99	6,901	3.25	51.19	33.18	Carboniferous	"Coal Meas."	Mixed.
120	Ala. 5.	La Salle.	B.	1.09	4.28	5.37	66.91	12.61	9.74	2.99	6,914	4.36	45.63	40.27	do.	do.	Lump.
121	Ala. 8.	Benton.	B.	1.33	1.46	4.40	69.64	6.35	16.82	3.00	6,920	1.24	55.74	26.20	do.	Pottsville.	Run of mine.
122	Ark. 1B.	Huntington.	B.	1.55	1.62	4.90	69.00	11.94	10.99	3.01	6,829	3.89	51.94	33.18	do.	"Coal Meas."	Egg coal.
123	Ill. 28C.	Herrin.	Sb.	1.46	1.14	3.88	69.25	4.03	19.26	3.02	6,770	8.85	63.64	16.25	do.	do.	Slack.
124	Ind. T. 2B.	Harrison.	B.	1.23	1.36	4.88	69.54	12.08	10.29	3.02	6,849	1.44	49.41	30.77	do.	do.	Lump.
125	Ind. T. 2B.	Brilliant.	B.	1.72	1.88	5.11	69.15	7.71	15.03	3.04	6,915	4.93	54.11	34.04	do.	do.	Slack.
126	N. Mex. 4A.	Brilliant.	B.	1.53	6.2	5.03	69.86	9.19	13.77	3.04	6,934	1.77	49.25	35.23	Cretaceous	Montana	Lump.
127	Ill. 12D.	Bush.	B.	1.22	2.70	4.75	68.81	11.54	10.93	3.05	6,910	2.91	49.54	32.51	Carboniferous	"Coal Meas."	Mine.

128	Wash. 2.	Roslyn.	1.26	38	5.08	70.26	10.60	12.42	3.05	7,084	1.88	48.73	36.57	Do.
129	Ky. 7.	Central City	1.32	2.71	5.06	67.80	12.34	9.77	3.06	6,863	3.57	46.26	36.33	Lump.
130	Ky. 2.	Earlington	1.25	3.72	5.03	67.64	12.68	9.38	3.06	6,966	5.36	46.27	38.99	Coarse coal.
131	Ohio II.	Fishing	1.19	4.39	4.71	67.72	8.84	13.15	3.08	6,937	1.87	48.35	36.63	Lump.
132	Ind. 18A.	Winslow	1.38	1.69	5.48	69.08	15.17	7.20	3.08	6,898	8.29	48.28	36.23	do.
133	Ky. 9A.	McHenry	1.24	3.25	4.41	68.01	12.80	9.29	3.08	6,953	5.39	49.05	36.27	do.
134	Ala. 3.	Garnsey	1.15	.56	4.47	70.84	8.45	14.53	3.08	7,007	1.54	54.11	29.82	Pottsville.
134a	Colo. 3541.	Book Cliffs field	1.58	3.10	5.17	69.83	16.47	6.11	3.09	6,978	3.61	51.49	36.77	Mesaverde.
135	Ky. 9B.	McHenry	1.39	8.07	5.04	68.35	11.59	10.50	3.09	6,985	6.01	51.49	36.77	Mine sample.
135a	Ind. 19B.	Ziegler	1.56	.64	4.51	70.55	13.11	8.67	3.10	6,897	4.93	55.19	31.31	Run of mine.
136	Ind. 15.	Linton	1.56	1.00	5.11	69.89	13.47	8.93	3.11	6,979	3.97	50.82	35.28	Run of mine.
136a	Colo. 3640.	Book Cliffs field	1.20	.49	5.38	70.32	16.87	5.74	3.11	6,908	5.21	55.69	33.36	Shallow mine sample.
137	Ind. T. 3.	Edwards	1.50	3.67	4.85	68.18	10.52	11.28	3.12	6,927	3.45	47.82	37.45	Run of mine.
138	Kans. 4.	Atchison	1.07	8.33	5.04	65.02	7.91	12.63	3.16	6,854	3.57	46.80	37.00	Lump.
139	Ill. 16.	Herrin	1.56	1.19	4.94	70.14	12.17	10.00	3.16	6,921	4.61	54.05	31.35	do.
140	Va. 5A.	Blacksburg	.69	.66	3.60	72.23	4.02	18.80	3.16	6,929	7.73	69.92	10.55	Pocono.
141	N. Mex. 5.	Blacksburg	1.19	.70	4.79	70.99	7.59	14.78	3.17	7,065	1.34	51.58	32.30	Montana.
142	Ind. 7.	Littles	1.25	3.88	5.40	67.99	11.93	9.55	3.17	6,920	5.50	44.99	39.96	Coal Meas.
143	Kans. 1.	Fleming	1.09	4.34	4.91	68.22	8.30	13.14	3.18	6,891	6.74	50.01	33.11	do.
144	Wyo. 5.	Rock Springs	1.29	.86	5.37	70.30	18.32	3.63	3.20	6,955	6.00	51.68	38.69	Montana.
145	Ind. T. 1.	Cartersville	1.39	2.07	4.84	69.91	10.64	11.15	3.21	6,978	1.11	52.71	33.03	Coal Meas.
146	Colo. 3946.	Henryetta	1.63	71	5.32	70.00	15.74	6.39	3.22	7,075	3.87	50.05	35.73	do.
146b	Colo. 3589.	Rifle Creek	1.63	1.31	5.33	70.00	15.34	6.39	3.22	7,075	4.24	53.04	37.24	Mesaverde.
146c	Wyo. 4302.	Willow Creek	1.55	.64	4.65	71.09	15.74	5.48	3.22	6,911	4.51	54.85	34.20	do.
147a	Colo. 3948.	Ziegler	1.48	.96	4.96	70.20	15.63	6.09	3.23	6,872	5.42	53.03	31.63	Benton.
147b	Cal. 3773.	Stone Canyon	1.19	4.26	5.14	69.50	14.50	6.37	3.23	7,086	4.86	41.03	47.74	Coal Meas.
148	Ind. 19B.	Willow Creek	1.55	.64	4.65	71.09	15.74	5.48	3.24	7,086	4.86	41.03	47.74	Mesaverde.
149	Ind. 7B.	Danford	1.24	4.14	5.11	68.94	10.34	10.23	3.26	6,947	4.16	50.17	34.84	do.
149a	Colo. 3546.	Littles	1.60	.74	5.38	71.03	15.16	6.09	3.34	7,069	2.76	46.55	40.46	

a Coals more or less weathered.

TABLE 1.—Ultimate analyses of 319 American coals, "air-dried" basis, from the chemical laboratory of the U. S. Geological Survey, with calorific value and C: (O+ash) ratio of each coal—Continued.

No.	Designation of coal.	Locality.	Kind.	N.	S.	H.	C.	O.	Ash.	$\frac{C}{O+ash}$	Calo-ries.	Mois- ture.	Fixed car- bon.	Vola- tile mat- ter.	Age.	Formation.	Remarks.
164	Tenn. 8A.	Clifty	B.	1.17	4.45	4.67	70.45	5.50	13.64	3.68	7,179	1.05	51.26	34.05	Carboniferous.	Pottsville.	Lump.
165	Ill. 34A.	Harrsburg	B.	1.53	2.51	4.96	71.55	10.55	8.90	3.68	7,824	2.13	53.36	35.61	do.	"Coal Meas."	Screenings.
166	Ala.	Belle Effen	B.	1.25	1.14	4.89	73.06	5.96	13.67	3.72	7,287	4.98	55.13	30.22	do.	Pottsville.	Run of mine.
166a	Colo. 3857	Book Cliffs field.	B.	1.65	3.04	5.24	72.46	13.12	6.05	3.77	7,207	4.17	52.20	37.58	Cretaceous.	Mesaverde.	Country bank.
167	Ohio 12B.	Bellaire	B.	1.25	3.70	5.07	71.13	8.75	10.10	3.77	7,280	2.69	50.10	38.11	Carboniferous.	"Coal Meas."	Lump.
168	Ohio 10.	Mineral City	B.	1.32	3.00	5.35	71.28	11.14	7.71	3.78	7,368	1.24	48.55	41.50	do.	do.	Run of mine.
169	Pa. 6.	East Millsboro.	B.	1.27	1.76	4.99	72.87	6.33	12.78	3.78	7,301	2.27	53.52	32.43	do.	do.	do.
170	Ill. 11C.	Carverville.	B.	1.43	1.76	4.99	72.80	10.84	8.18	3.82	7,263	2.36	54.84	34.62	do.	do.	do.
170a	Ohio 9A.	Clarton.	B.	1.22	3.25	4.67	72.07	10.23	8.56	3.83	7,331	2.73	53.00	38.08	do.	do.	Lump.
171a	Colo. 3338	Newcastle.	B.	1.76	5.54	5.05	73.45	14.22	4.98	3.83	7,429	4.78	52.69	37.20	Cretaceous.	Mesaverde.	Mine sample.
171b	Colo. 3385	Book Cliffs field.	B.	1.63	4.42	5.52	72.62	13.53	5.33	3.91	7,364	3.19	55.49	35.91	do.	do.	Do.
171c	Colo. 3392	Newcastle.	B.	1.45	4.22	5.21	73.98	13.53	5.41	3.91	7,364	3.19	55.49	35.91	do.	do.	Do.
172	Ohio 12A.	Bellaire	B.	1.23	4.07	5.03	71.44	8.60	9.63	3.92	7,343	1.88	48.44	40.35	Carboniferous.	"Coal Meas."	Run of mine.
173	Kans. 5.	West Mineral	B.	1.09	3.86	4.96	71.90	7.40	10.79	3.95	7,333	1.84	54.97	32.40	do.	do.	Screened.
173a	Wyo. 3570.	Oyster Ridge	B.	1.18	4.48	5.10	74.41	14.36	4.47	3.95	7,333	3.84	55.47	36.06	Cretaceous.	Benton.	Prospect.
173b	Colo. 3339	Newcastle.	B.	1.73	5.22	5.17	73.87	13.62	5.09	3.95	7,441	2.90	53.35	38.66	do.	Mesaverde.	Mine sample.
174	Tenn. 4.	Oliver Springs.	B.	1.63	5.03	5.49	73.65	16.61	1.94	3.97	7,433	1.77	54.32	33.91	Carboniferous.	Pottsville.	Run of mine.
174a	Colo. 4036	North of Sunlight.	B.	1.78	5.53	5.49	73.65	16.61	1.94	3.97	7,465	4.18	54.03	39.25	Cretaceous.	Mesaverde.	Mine sample.
175	W. Va. 22B.	Hernshaw	B.	1.18	1.04	5.69	73.73	12.18	5.87	4.08	7,344	1.74	53.80	34.37	Carboniferous.	Pottsville?	Run of mine.
175a	Colo. 4225	Near Mancos.	B.	1.50	1.03	5.69	73.73	12.18	5.87	4.08	7,448	1.09	57.87	28.71	Cretaceous.	Mesaverde.	Shallow mine.
176	Pa. 17.	White.	B.	1.44	1.56	4.83	74.06	5.80	12.31	4.08	7,461	3.53	53.77	37.08	Carboniferous.	"Coal Meas."	Run of mine.
176a	Colo. 7573	Hesperus.	B.	1.40	1.66	5.32	74.61	12.39	5.82	4.08	7,601	1.95	54.42	36.24	Carboniferous.	Mesaverde.	Mine sample.
177	Ohio 4.	Spring Hill	B.	1.33	3.52	5.02	72.68	10.89	7.39	4.08	7,608	2.16	50.61	37.98	Carboniferous.	"Coal Meas."	Lump.
178	Ohio 4.	Crow Hollow	B.	1.33	3.52	5.02	72.68	10.89	7.39	4.17	7,365	2.16	50.61	37.98	do.	do.	Screened.
179	Ark. 8.	Spadra.	Sa.	5.3	2.14	3.44	75.77	3.47	14.65	4.18	7,244	3.10	55.32	38.58	do.	Mesaverde.	Stove coal.
179a	Colo. 4048	Sunlight.	B.	1.86	9.16	5.36	74.10	14.72	3.00	4.18	7,564	3.83	57.48	32.01	Cretaceous.	"Coal Meas."	"D" bed.
180	Ky. 8.	Sturgis.	B.	1.23	1.22	4.87	74.99	9.51	8.18	4.24	7,598	2.22	68.58	16.68	Carboniferous.	"Coal Meas."	Run of mine.
181	Ark. 12.	Sturgis.	B.	1.38	1.22	4.87	74.99	9.51	8.18	4.24	7,282	1.22	68.58	16.68	do.	do.	Slack.
182	Ark. 1.	Huntington.	Sb.	1.47	1.27	4.00	75.68	4.40	12.88	4.30	7,450	1.17	68.12	17.83	do.	do.	Screened.
183	Ohio 5.	Rush Run.	Sb.	1.45	1.76	5.06	74.44	9.81	7.48	4.31	7,501	1.99	54.13	36.40	do.	do.	do.
184	Utah 1.	Potosi.	B.	1.43	3.38	4.97	73.23	12.21	5.06	4.35	7,595	2.34	48.92	43.68	Cretaceous.	Mesaverde.	Run of mine.
185	Tenn. 5.	Potosi.	B.	1.69	3.58	4.97	73.23	6.53	10.20	4.37	7,595	1.35	53.32	35.13	Carboniferous.	Pottsville.	Do.
186	Tenn. 3.	Gatlin.	B.	1.78	1.02	5.31	74.80	9.81	7.28	4.38	7,489	2.25	54.79	35.68	do.	do.	Do.
187	Ohio 6.	Nefs.	B.	1.17	3.05	5.16	73.58	7.76	8.87	4.42	7,425	1.47	51.45	38.21	do.	"Coal Meas."	Lump.
188	Ind. T. 2C.	Hatshorne.	B.	1.88	1.03	5.03	74.50	8.87	8.49	4.45	7,505	1.43	53.08	36.62	do.	do.	Run of mine.
189	Pa. 22.	Huf.	B.	1.51	3.25	4.77	75.69	6.44	10.49	4.47	7,632	1.94	69.40	16.34	do.	do.	Do.
190	Md. 1.	Georges Creek.	Sb.	1.32	1.51	4.77	74.89	7.36	9.32	4.49	7,469	1.27	58.64	30.77	do.	do.	Do.
191	Pa. 12.	Acheson.	Sb.	1.46	2.21	3.86	76.28	3.69	13.32	4.49	7,621	1.45	56.40	34.17	do.	do.	Screenings.
192	W. Va. 22A	Hernshaw	B.	1.22	1.85	5.05	76.01	8.89	7.98	4.50	7,645	1.52	56.40	34.17	do.	"Coal Meas."	Run of mine.
193	Pa. 7.	Ligonier.	B.	1.55	2.15	4.51	75.19	3.72	12.88	4.52	7,549	1.45	64.90	21.30	do.	do.	do.

194	Tenn. 9C.	Coalmont.....	1.28	.67	4.83	76.37	7.27	9.58	4.54	7,563	1.43	59.26	29.73	do.	Pottsville	Run of mine.
195	Ark. 3	Jenny Lind.....	1.55	1.30	4.07	76.37	4.91	11.80	4.57	7,563	.80	67.65	19.75	do.	"Coal Meas."	Run of mine.
196	Pa. 21	Connetsville.....	1.57	.90	4.82	76.34	7.47	9.09	4.61	7,751	.97	60.85	29.09	do.	do.	Lump.
197	Pa. 4	Greensburg.....	1.46	1.29	4.63	76.00	5.78	10.64	4.62	7,616	.97	57.44	30.95	do.	do.	Run of mine.
198	W. Va. 3	Richard.....	1.44	1.07	5.04	76.02	6.09	10.37	4.64	7,631	1.00	58.38	30.25	do.	do.	Run of mine.
199	W. Va. 23B	Monarch.....	1.19	1.36	5.04	76.02	8.24	8.15	4.62	7,661	1.46	55.47	34.62	do.	Pottsville	Slack.
200	W. Va. 5	Coalton.....	1.48	.99	4.78	76.26	6.21	10.18	4.65	7,652	.65	59.97	29.20	do.	"Coal Meas."	Coarse coal.
201	W. Va. 10	Monongah.....	1.53	1.20	4.80	76.09	7.56	8.76	4.66	7,609	1.22	56.96	33.06	do.	do.	Screenings.
202	Pa. 19	Hermine.....	1.42	1.08	4.92	76.25	7.76	8.57	4.67	7,752	1.01	57.85	32.57	do.	do.	Run of mine.
203	Mo. 4	Barnet.....	1.75	5.55	5.77	72.45	10.25	5.23	4.68	7,516	5.39	44.47	44.91	do.	do.	Do.
204	Ky. 1B	Straight Creek.....	1.73	1.16	5.06	74.44	7.70	7.90	4.69	7,623	1.47	50.50	40.14	do.	"Coal Meas."	Do.
205	W. Va. 2	Clarksburg.....	1.32	2.12	3.99	76.37	3.91	12.29	4.70	7,700	1.86	70.00	17.11	do.	do.	Slack.
206	Ark. 7A	Midland.....	1.81	1.01	5.02	76.84	7.03	8.54	4.71	7,413	1.95	54.05	36.97	do.	do.	Run of mine.
208	W. Va. 4B	Bretz.....	1.81	1.10	4.52	76.84	12.64	3.23	4.77	7,626	1.35	60.88	27.39	do.	Pottsville	Run of mine.
208a	Wyo. 4803	Willow Creek.....	1.31	.94	5.16	77.05	9.46	6.32	4.84	7,812	1.99	57.53	37.18	do.	"Coal Meas."	Do.
208b	Colo. 4010	Gulch.....	1.56	.45	4.50	76.64	7.20	8.48	4.88	7,860	1.21	59.43	30.90	do.	Benton	Prospect.
209	Ala. 3499	Lovick.....	1.69	1.10	4.89	76.64	7.20	8.48	4.88	7,613	1.19	57.30	35.17	do.	Messaverde	Mine sample.
210	W. Va. 28A	Richlands.....	1.45	1.24	5.14	76.57	7.90	7.71	4.90	7,643	1.58	55.50	35.21	do.	Pottsville	Run of mine.
210a	Ala. 3745	Monarch.....	1.33	1.27	4.43	77.21	5.45	10.30	4.90	7,757	.65	64.77	24.28	do.	do.	Do.
211	Ark. 5	Coalmont.....	1.13	.88	5.04	77.29	3.36	12.21	4.96	7,764	1.67	59.11	32.92	do.	"Coal Meas."	Mine sample.
211a	Colo. 3552	Coal Hill.....	1.39	2.01	3.78	77.42	9.89	5.31	4.96	7,443	2.07	54.22	38.40	do.	Messaverde	Run of mine.
212	Pa. 9	Near Durango.....	1.29	2.09	4.00	77.42	3.58	11.63	5.09	7,657	.50	70.12	17.75	do.	"Coal Meas."	Run of mine.
213	W. Va. 11	Kimmelton.....	1.04	.53	4.03	79.12	3.78	11.50	5.17	7,761	.80	70.80	16.90	do.	Pottsville	Run of mine, Poca-hontas.
214	Pa. 11	Zenith.....	1.45	1.19	5.09	77.52	7.62	7.33	5.17	7,699	1.36	57.03	34.28	do.	"Coal Meas."	Run of mine.
215	W. Va. 15	Charterol.....	1.44	2.56	5.09	76.52	5.82	8.63	5.29	7,743	1.12	52.60	37.65	do.	do.	Pittsburg.
215a	Wyo. 4299	Clarksburg.....	1.85	.71	5.59	78.19	11.18	3.48	5.33	7,713	2.37	37.33	36.79	do.	do.	Do.
216	W. Va. 14	Willow Creek.....	1.50	.90	4.44	78.21	6.11	8.43	5.37	7,855	1.86	61.87	28.72	do.	Benton	Tunnel.
216a	Ala. 3771	Bretz.....	1.53	.44	5.13	78.67	8.46	5.75	5.53	7,791	1.93	58.75	33.04	do.	"Coal Meas."	Run of mine.
217	Va. 4	Acton basin.....	1.55	.81	4.58	78.56	9.73	4.42	5.55	7,902	2.40	55.54	37.64	do.	Pottsville	Helena coal.
218	Va. 2B	Darby.....	1.45	.94	5.13	78.56	8.33	6.69	5.59	7,990	1.48	57.02	25.81	do.	do.	Run of mine.
219	W. Va. 1	Crab Orchard.....	1.55	.90	5.26	78.31	7.61	6.37	5.60	7,869	1.35	55.36	26.92	do.	do.	Do.
220	Pa. 10	Kingmont.....	1.59	1.23	5.14	78.16	7.58	6.25	5.64	7,877	1.33	57.04	25.38	do.	"Coal Meas."	Nut.
221	Va. 1	Crab Orchard.....	1.27	1.23	5.07	78.47	9.01	8.85	5.66	7,870	1.70	57.66	25.79	do.	do.	Run of mine.
222	W. Va. 20	Acme.....	1.37	1.41	5.17	78.47	5.59	8.20	5.68	7,812	.74	58.17	32.53	do.	do.	Do.
223	W. Va. 8	Ansted.....	1.38	.92	5.16	78.75	6.43	7.36	5.78	7,963	1.00	58.92	32.12	do.	do.	Do.
224	Ky. 6	Miller Creek.....	1.48	.58	5.25	78.94	10.83	2.82	5.78	7,507	2.93	56.88	37.31	do.	"Coal Meas."	"Splint."
225	W. Va. 17	Near Bretz.....	1.41	1.49	4.51	78.95	5.41	8.33	5.78	7,903	1.00	62.68	27.99	do.	do.	Prospect.
226	Pa. 5	Ellsworth.....	1.55	.50	5.20	78.78	7.47	6.11	5.80	7,864	1.47	57.49	34.83	do.	do.	Screened.
227	Pa. 16	Hastings.....	1.33	1.65	4.46	79.00	5.57	8.19	5.83	7,812	.76	63.78	22.67	do.	do.	Pittsburg.
227a	Ala. 3769	Acton basin.....	1.25	1.10	5.01	79.16	8.83	4.65	5.87	7,964	1.62	59.87	33.86	do.	Pottsville	Run of mine.
228	Pa. 20	Seward.....	1.16	2.96	4.55	78.23	2.17	10.93	5.90	7,692	4.62	72.17	16.48	do.	"Coal Meas."	Helena coal.
229	Ky. 1	Straight Creek.....	1.85	1.24	5.26	78.31	8.50	4.44	5.91	7,955	1.92	57.08	36.56	do.	Pottsville	Run of mine.
230	Pa. 15B	Wehrum.....	1.18	4.06	4.29	77.52	2.00	10.55	5.98	7,781	.88	70.49	18.48	do.	do.	Do.
231	W. Va. 18	Glen Alum.....	1.45	.68	4.91	79.50	7.39	5.92	5.98	7,963	1.28	59.03	33.77	do.	Pottsville	Do.
231a	Ala. 3744	Falston.....	1.33	.67	5.21	79.50	10.03	3.21	6.01	8,115	1.52	60.68	34.59	do.	do.	Buck bed.
231b	Colo. 4047	Coal basin.....	1.83	.52	4.65	79.77	4.59	8.64	6.03	7,977	.76	69.07	21.53	do.	Messaverde	Run of mine.

b Coals more or less weathered.

a From shallow mine or country bank.

TABLE 1.—Ultimate analyses of 319 American coals, "air-dried" basis, from the chemical laboratory of the U. S. Geological Survey, with calorific value and C:(O+ash) ratio of each coal—Continued.

No.	Designation of coal.	Locality.	Kind.	N.	S.	H.	C.	O.	Ash.	$\frac{C}{O+ash}$	Calo-ries.	Mois-ture.	Fixed-car-bon.	Vola-tile-mat-ter.	Age.	Formation.	Remarks.
232	W. Va. 9.	Powellton.	B.	1.63	.80	5.04	79.35	6.39	6.79	6.03	7,984	1.01	62.67	29.53	Carboniferous.	Pottsville	Run of mine.
233	Ky. 5.	Big Black Mountain.	B.	1.61	.69	4.99	79.67	9.23	3.81	6.10	7,958	1.60	58.56	36.03	do.	do.	"Splint," pro- spect.
234	W. Va. 21.	Winifrede.	B.	1.52	1.35	5.21	79.15	7.83	4.95	6.19	7,915	1.50	56.39	37.16	do.	do.	Run of mine, Winifrede coal.
235	Ala. 6.	Dolomite.	B.	1.45	.63	4.84	80.25	5.94	6.88	6.26	8,011	.85	65.47	26.80	do.	do.	Run of mine, Pratt coal.
236	Ark. 2.	Bonanza.	Sb.	1.40	1.90	4.13	80.03	3.20	9.34	6.38	7,756	.74	73.66	16.26	do.	do.	Run of mine.
237	Pa. 15.	Wehrum.	Sb.	1.17	3.88	4.43	78.61	1.82	10.09	6.60	7,885	.34	71.45	18.12	do.	do.	Run of mine.
238	Pa. 18.	Lloyd.	Sb.	1.23	1.55	4.53	80.74	3.02	8.83	6.81	7,926	.38	74.69	16.00	do.	do.	Do.
239	W. Va. 14.	Loup Creek.	B.	1.56	1.06	5.15	80.73	8.12	2.38	7.01	8,060	2.05	64.57	30.00	do.	Pottsville.	Do.
239a	Ark. 3174.	Paris.	Sa.	1.49	2.85	3.87	80.48	2.04	9.27	7.11	7,824	.59	75.12	15.02	do.	"Coal Meas."	L. Kittanning coal.
239b	Pa. "L."	Johnstown.	Sb.	1.27	2.29	4.04	81.10	2.99	8.31	7.18	7,934	.64	76.38	14.67	do.	do.	Run of mine, Sewell coal.
240	W. Va. 7.	Sun.	Sb.	1.05	1.20	4.38	82.41	5.87	5.09	7.52	8,254	.76	73.61	20.54	do.	Pottsville.	Run of mine, Pittsburg coal.
241	Md. 2.	Frostburg.	Sb.	1.49	.86	4.54	82.39	3.43	7.29	7.68	8,086	.74	73.83	18.14	do.	do.	Wadsworth coal.
242	Ind. T. 9.	Panama district.	Sa.	1.68	1.24	4.35	82.06	2.26	8.41	7.69	7,948	.64	76.66	14.29	do.	do.	Screened.
242a	Ala. 3770.	Sydenon.	B.	1.55	.49	5.34	82.09	6.09	3.84	7.79	8,180	1.28	60.32	34.56	do.	Pottsville.	Run of mine.
243	Va. 3.	Coeburn.	B.	1.63	.68	4.04	82.16	5.91	4.58	7.83	8,220	.87	62.19	32.36	do.	do.	Do.
244	Pa. 8.	Ehrenfeld.	Sb.	1.29	.97	4.37	83.11	3.43	6.83	8.10	8,170	1.17	62.95	17.32	do.	"Coal Meas."	Run of mine.
245	W. Va. 13.	Page.	B.	1.36	.91	5.15	82.65	5.91	4.01	8.32	8,234	1.62	74.38	18.05	do.	Pottsville.	Do.
246	W. Va. 12A.	Big Sandy.	Sb.	1.34	.69	4.36	83.63	3.03	6.95	8.38	8,185	.80	62.95	18.05	do.	do.	Briquettes.
247	W. Va. 12B.	do.	Sb.	1.33	.85	5.05	83.62	3.36	6.22	8.68	8,300	1.93	62.95	21.74	do.	do.	Run of mine.
248	W. Va. 6.	Rush Run.	Sb.	1.70	.66	4.70	83.62	4.23	5.09	8.97	8,203	.68	70.91	23.28	do.	do.	Run of mine, Sewell coal.
249	W. Va. 19.	McDonald.	Sb.	1.60	.91	4.66	83.56	4.13	5.13	9.01	8,203	.68	70.91	23.28	do.	do.	Run of mine, Sewell coal.
250	W. Va. 10.	Mora.	Sb.	1.07	.57	4.53	85.91	3.24	4.63	10.91	8,439	.65	75.92	18.80	do.	do.	Pocantotas; pro- spect.

## ARRANGEMENT OF ANALYSES.

It must be borne in mind that the analyses in this table are arranged according to the numerical sequence of the C:(O + ash) ratios of the samples. The calorific values determined directly from the same air-dried samples by the Mahler bomb calorimeter are set down in the column adjoining that of the ratios. Most of the calorific determinations were made in duplicate.

It will be remembered that in the ultimate analyses of air-dried samples, such as are here considered, the highly variable remaining moisture is included in the percentages of hydrogen and oxygen. Therefore in many cases the greater part of the oxygen of the analysis belongs to the retained moisture. The amount of moisture, as set down to the right of the calories column in the table, varies from 26.64 (No. 3, N. Dak., 3) to 0.34 (No. 237, Pa., 15). The fixed carbon and "volatile combustible matter" ascertained from the proximate analyses, also on the air-dried basis, are placed next beyond the moisture column. It will be seen that the percentages of ash range from 29.33 (No. 21, Mexico) to 2.38 (No. 239, W. Va., 14); and of oxygen from 38.57 (No. 2b, Wyo., 3694<sup>a</sup>) to 1.82 (No. 237, Pa., 15). The arrangement of coals so widely varying in these two respects purely on the basis of the numerical sequence of the C:(O + ash) ratios results in a mingling of fuels of very different kinds, characters, and ages, even bringing low-grade subbituminous coals (black lignites) into incongruous juxtaposition with Paleozoic coals of advanced devolatilization, the high oxygen of the former being balanced by the high ash of the latter.

## FUELS HIGH IN OXYGEN OR ASH.

To show by specific illustrations the relative importance of oxygen and ash as indicated by the calorimetric tests, a few of the more conspicuous examples may be cited from Table 1: No. 8 (N. Dak., 1), from the Tertiary, has oxygen 27.15 and ash 12.24, the ratio of the carbon to them being 1.31; while No. 10 (Ind. T., 5), from the "Coal Measures," has oxygen 12.40 and ash 25.75, the ratio of carbon being 1.37. In these two analyses the oxygen and ash are contrastingly paired. The difference between the calorific values of the two coals is not far from the value corresponding to the difference between the two ratios, as will be shown later. No. 25, a Fort Union coal, at Monarch, Wyo., shows oxygen 28.99 and ash 4.79; while in No. 27, from Ozone, Tenn., the percentages are nearly reversed, oxygen being 4.90 and ash 28.53. The difference between the calorific values of

---

<sup>a</sup> The abnormally high oxygen of this Wyoming coal is the result of weathering. For an oxygen content nearer normal, see No. 5 (N. Dak., 2B), with 35.86; or No. 25 (Wyo., 1), with 28.99. That several of the lignites show more oxygen than the peats is due to the lesser moisture in the peat samples.

these two coals accords within 1 per cent with the value corresponding to the difference in their C:(O + ash) ratios. Again, No. 30, a bony layer high in ash in the Pocahontas (lower Pottsville) bed, at Gary, W. Va., and No. 32, a Laramie coal, at Lafayette, Colo., are nearly paired, the oxygen being 3.97 and 24.95, respectively, and the ash 28.77 and 6.32; neither of the calorific efficiencies differs 0.75 per cent from the calorific values corresponding to the carbon ratios. A still closer agreement with No. 32 is presented by No. 35, from Bonanza, Ark.; the fixed carbon in pure coal of the latter is 78.97, while that of No. 32 is but 53.69. The Paisley, Ill. (No. 42), and the Sprague, Mo. (No. 43), coals have oxygen contents of 16.1 and 8.46, respectively, their ash being 13.10 and 20.38; as compared with the calorific values corresponding to the respective ratios,<sup>a</sup> 2.06 and 2.08, the former has a deficiency of 36 calories, the latter an excess of 25. The agreement of No. 41 (Hanna, Wyo.) with the coals just cited is equally close in spite of its low ash, the ascertained calories being but 14 less than the number corresponding to its ratio, 2.04. An almost equal agreement in calorific values is shown in the contrasting analysis, No. 64, from the Upper Cretaceous, at Gallup, N. Mex., and No. 65, from the "Coal Measures," at Yale, Kans.,<sup>b</sup> in which the oxygen is 21.14 and 5.13 and the ash 7.10 and 21.82, respectively. The error is not much greater between No. 100, from the Upper Cretaceous, at Van Houten, N. Mex., and No. 101, from the Carboniferous, at Dugger, Ind., in both of which the oxygen, at 9 and 15.76, is balanced by ash, 15.74 and 8.48.

#### FUELS OF LOWER ASH AND OXYGEN.

Passing on to coals of better quality, similar comparisons may be made between 119, 120, and 121, in which there is marked alternation in the amounts of these impurities, though the total difference in the efficiency is less than 20 calories. A greater contrast in age and character of the samples is found in No. 140, from the basal Mississippian ("Lower Carboniferous"), at Blacksburg, Va., and No. 144, from the Upper Cretaceous, at Rock Springs, Wyo. In the former the proportions are oxygen 4.02, ash 18.80; in the latter, oxygen 18.32 and ash 3.63. The Virginia coal is semianthracite, with a fixed carbon in pure coal of 86.89; the Wyoming is a sub-bituminous coal, having a fixed carbon of but 57.19. These have efficiencies, the first 33 and the other 30 calories less than the values corresponding to their respective ratios, 3.16 and 3.20. The efficiencies of No. 153, from the Indiana coal field, and No. 155, from the Ten-

<sup>a</sup> For calorific values corresponding to the ratio means, and for percentage ratios of volatile carbon, fixed carbon, available hydrogen, etc., see the same numbers in Table 2 (pp. 26-33).

<sup>b</sup> Unusually high available hydrogen compensated by very high sulphur.

nessee Pottsville, appear to conform very nearly to the means corresponding to the ratios, although the coals offer marked alternation in oxygen and ash. The Huntington, Ark., coal (No. 182) has a fixed carbon (in pure coal) of 79.25, and a Mesaverde coal, at Price, Utah (No. 184), but 52.68. The oxygen and ash nearly reciprocate at 4.70 and 12.88 against 12.21 and 5.06, the ratios being 4.30 and 4.35, respectively. The Huntington coal appears to have a deficiency of 60 calories, while the Utah coal has an equal number in surplus, the variance in either case being not more than 0.8 per cent of the calorific value.

Not to weary the reader with the details of further illustrations, a few additional comparisons are suggested as follows: Nos. 185 and 186; 193, 194, and 195; 199 and 200; 216 and 218; also Nos. 165 and 167; 131 and 132; 94 and 95; 39 and 40.

The more conspicuous contrasts noted in so many of these analyses naturally involve great differences in the kind and stage of development or maturity of the compared coals, whose proximate association in the table is due to the sequence of the ratios. The regularity of the coals with similar analyses, though from different regions or of different kinds, is well illustrated by Nos. 60 to 63; 91 and 92; 145 and 146; 173 and 174; and 220 to 223.

#### RELATION TO CALORIFIC VALUE.

However conspicuous or striking the contrasts offered by the examples specially cited above, the essential and most important evidence for the approximately equivalent negative values of oxygen and ash lies in the relatively close conformity, throughout the whole series, of the ascertained calorific values to the C:(O+ash) ratios; so that not only do coals having the same ratio closely approach the same efficiency values, but also the latter arrange themselves mainly in accordance with the sequence of the ratios. This may readily be noted in the series 25-50; 60-70; 87-125; 139-145; 164-176a; 182-201; 211a-226; and 241-250.

It must not be forgotten that in this treatment the hydrogen, sulphur, and nitrogen are assumed to be constant and therefore negligible; also that the oxygen of the analyses includes the oxygen of moisture as well as that really of the coal—that is, presumably in hydrocarbon combination.

The nearness to equality in the negative values of oxygen and ash is indicated fairly distinctly in Table 1. In a later section it will become more distinct, in connection with the discussion of the limits of variation from the ratio means, and the effect of the neglected "constants" as a cause of variance from a strict sequence in the calorific values.

## CURVE PLATTED FROM C:(O+ASH) RATIOS AND EFFICIENCIES.

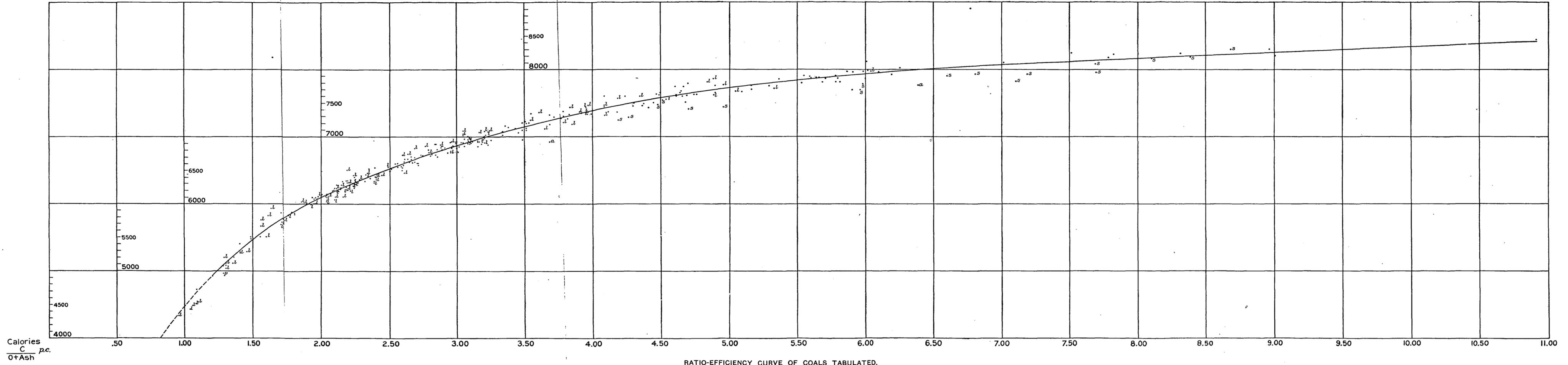
## DETERMINATION OF CURVE.

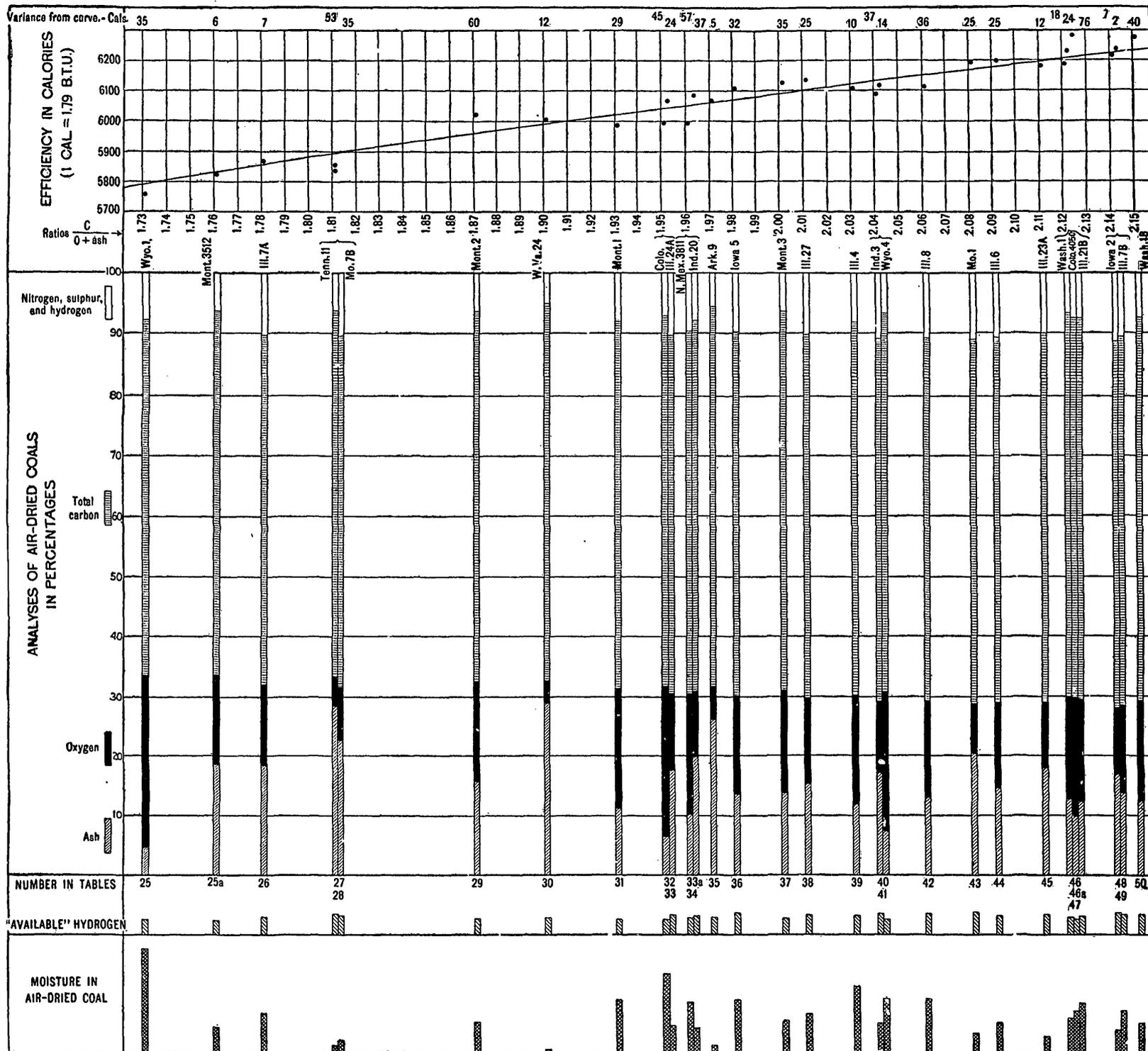
In order to ascertain the mean calorific values corresponding to the various ratios, the efficiencies of all the coals in the tables have been platted in Plate I. The horizontal component is the C:(O+ash) ratio; the vertical is the heat value shown in the calorimeter tests. As thus platted the efficiencies are seen to describe a very clear and narrowly defined curve. The line in the figure is arbitrarily drawn to conform to the trend of this curve. Before proceeding, it may be remarked that the lower end of the curve is provisionally left dotted on account of the small number of wholly satisfactory analyses of the lowest grade coals, many samples having been more or less affected by exposure to the air. Also at the upper end additional analyses are needed for its more exact determination.

Considering that the hydrogen, sulphur, and nitrogen contents are here absolutely ignored and treated as negligible constants, the comparative proximity and regularity in the distribution of the efficiencies along the course of the curve is certainly remarkable. This regularity is explained (see p. 44) as due to the dominant control of the carbon, on the one hand, balanced by the chief impurities, oxygen and ash, on the other, in determining the calorific efficiencies of the ordinary types of the fuels, the hydrogen being either relatively stationary or, when in excess, more or less completely counteracted by relatively high sulphur, nitrogen, or unusually high ash, which may be slightly more deleterious than the oxygen. By referring to Table 1 it will be observed that the instances of wider departure from the curve are largely confined either to the weathered samples or to approaching anthracitization. The curve is particularly interesting because it is adjusted to a miscellaneous collection of coals of all grades, ages, and localities. It is not improbable that slight readjustments or special curves will be required for special groups of coals, like the cannels, or to suit the peculiarities of the coals of a given area.

## DETAILED STUDY OF A CURVE SEGMENT.

The relative values of oxygen and ash and the approximation of the curve are diagrammatically expressed in Plate II, which shows on a large scale a section of the curve, embracing Nos. 25-50 of Table 1. Several of the intercalated analyses of samples, in some instances weathered, collected by the field geologists and recently published in U. S. Geol. Survey Bulletin 316, are here omitted. All fuels tested by the Survey are, however, included. The samples represent coals in Wyoming, Montana, Illinois, Tennessee, Missouri, West Virginia, Colorado, New Mexico, Arkansas, Iowa, and Washington. For description of the kind and age of each coal the reader is referred





SEGMENT OF RATIO-EFFICIENCY CURVE.

to Table 1. The segment of the curve taken from Plate I occupies the upper part of the diagram. As in Plate I, the vertical component represents the calorific efficiency and the horizontal component represents the C:(O + ash) ratio of the coal.

The lower middle portion of the diagram shows the ash, oxygen, and carbon of the respective analyses, each analysis being platted in a position corresponding to that of its ratio in the horizontal component of the curve. The hydrogen, sulphur, and nitrogen, whose aggregate complete the 100 per cent in the analysis, are left blank and undifferentiated above the carbon. For information, what is termed "available" hydrogen  $\left(H - \frac{O}{8}\right)$  and the moisture contained in the air-dried coal are separately platted at the base of the diagram.

The disposition of the calorific values close along the line of the curve in Plate II seems to indicate (1) the approximately equal importance of oxygen and ash in impairing the efficiency of the coal in the calorimeter; (2) the relatively close agreement of the ascertained efficiencies to the C:(O + ash) ratio-efficiency curve; (3) the dominant control of the carbon, oxygen, and ash in determining the calorific value of the coal; and consequently (4) the relative constancy or negligibility of the other elements (assumed constants) nitrogen, sulphur, and hydrogen.

#### VARIATIONS FROM THE CURVE.

The curve errors—that is, the variations of the actually ascertained calorific values from the curve line—are noted, each in horizontal position corresponding to the analysis, at the upper border of the diagram. A review of these errors or variations shows an average departure of but 29 calories for the 29 analyses of the diagram.

In this connection it may be interesting to compare the calorimetrically determined values with those indicated by the curve and with the efficiencies as calculated from the chemical analyses. Reference to Professional Paper No. 48 of the Survey, in which such calculations of the efficiencies of coals were published, shows that eight of the samples which reappear in this diagram are included in that report.<sup>a</sup> The greatest variance in the chemical calculations of these eight analyses is 171 calories. The average variance is 89 calories. The average ratio-efficiency curve error for the same eight analyses, as shown in the diagram, is 23 calories; the highest individual error in the entire diagram is 76 calories.

The efficiency variance, that is, the variation of the calorimeter determination from the ratio C:(O + ash) efficiency curve—as read with

<sup>a</sup> Report on the operations of the coal-testing plant of the U. S. Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904: Prof. Paper U. S. Geol. Survey No. 48, 1906. The samples there included are as follows: No. 25, error + 171; No. 31, error + 119; No. 32, error + 136; No. 35, error + 60; No. 39, error + 44; No. 43, error - 15; No. 44, error + 140; No. 48, error + 29.

some care from the large-scale original of Plate I—is noted for each of the 319 analyses in a column at the right in Table 2. The curve drawn in the diagram (Pl. I) is not entirely regular nor mathematically correct, but it is probable that its subsequent correction, based on additional data, will have the effect of lowering the mean variances of the analyses as now platted. The calorific variances in Table 2 are therefore subject to revision. Omitting from further consideration the Rhode Island graphitized coal, which, being incombustible in its natural state, can not be regarded from the fuel standpoint as a coal, the highest error for an individual analysis is 312 calories, for the anthracite culm (No. 163) at Scranton. For the 318 analyses the average error is 67.2 calories. This includes the weathered coals and samples from shallow country banks and prospects, as well as the coals undergoing the final devolatilization marking anthracitization, all of which, as has already been observed, show relatively large errors. If, however, we but exclude 18 of the highest coals, embracing those having a fixed carbon of over 79 per cent in pure coal and a  $\frac{VC}{C}$  ratio of less than 9.25 (per cent) we shall have for the 300 remaining analyses a mean error of 60.09 calories. This average, it may be noted, does not exclude the weathered coals in the table.

#### COMPARISON WITH CALCULATED THERMAL UNITS.

Referring again to Professional Paper 48, in which the calorific values as calculated from the chemical analyses are published, we find that among the 57 ultimate coal analyses there given, all of which are included in Tables 1 and 2, the greatest individual error<sup>a</sup> is 312, as large as the maximum in all the coals of the tables, while the average error is 87.5 calories. The average ratio-efficiency curve error for the same 57 analyses, as shown in Table 2, is 58.7 calories. It may be proper to allow 2 or 3 calories additional to the average of Table 2 for personal equation in reading from the curve. In passing we may note that in very many cases the curve error appears to be less than the probable error of the calorimeter. The empirical anticalorific values of ash and oxygen as roughly calculated from the curve and the influence of sulphur in the coals are considered later (pp. 39, 44).

#### FORECAST OF FUEL EFFICIENCY FROM RATIOS.

The close relationship between the calorific values and the curve not only conclusively shows the nearly equal anticalorific values of the oxygen and ash, it also shows that the heat value of the coal as a whole is practically determined by the balance between these two principal impurities, on the one hand, and the total carbon on the other. The ordinary method of estimating the heat value of a coal,

<sup>a</sup> For West Virginia 6 (No. 248) a coking coal from Rush Run.

in accordance with Du Long's formula, generally used by chemists, is to calculate the sum of the heat units afforded by the carbon, hydrogen, and sulphur. The formula as recommended by the committee of the American Chemical Society is  $8080C + 34460 \left( H - \frac{O}{8} \right) + 2250S$ .<sup>a</sup>

The comparative study here presented demonstrates an approximate negative parity of oxygen and ash assumed in the application of Du Long's formula. It is surprising that a simple process like the ratio-efficiency curve which takes account only of the carbon, the preponderant source of heat units, and of the two great anticalorific ingredients of the fuel, should in a relative way so nearly indicate its calorific value. Such an effect seems explicable only (1) by the relatively uniform amount of heat contributed by the hydrogen as compared to that of the variable carbon, notwithstanding its great heating power; and (2) by the relatively constant negative potency, as well as proximity to anticalorific equality of ash and oxygen, whether the latter be in hydrocarbon combination or in the form of moisture. In this connection it may be noted that the calorific value in No. 2b is but 150 calories below the curve, though the coal contains no available hydrogen whatever, according to the analysis.

That the curve errors are not more exaggerated on account of the variability of the hydrogen, both in total amount and in the "available" form, is surprising. In the high-grade cannel, like that at Lesley, Ky. (H 6.82, C 73.54, O 7.95, ash 9.35, moisture 1.31), and in the bogheads, the relatively high hydrogen produces an efficiency considerably above the curve. For this class of coals either a coefficient for excess may be used or a higher curve drawn.

#### RELATIONS IN MOISTURE-FREE COALS.

##### RECALCULATION OF ANALYSES.

In Table 1 the analyses of the air-dried coals naturally included under the hydrogen and oxygen percentages the moisture remaining in the fuel. For the purpose of observing the true proportions of the oxygen and hydrogen assumed to belong to the moisture-free coals themselves it is necessary to take from the percentages this included moisture. In Table 2 the moisture is excluded from the oxygen and hydrogen columns. Yet in order to preserve the conformity of the analysis to the original air-dried status of the fuel, on the basis of which the calorific values were actually determined, the moisture is set down as a separate entry, included in the 100 per cent of the analysis. Ash, carbon, nitrogen, and sulphur remain as before. The fixed carbon and the volatile matter, as determined by the proximate analysis, are repeated from Table 1, as also are the C: (O + ash) ratios and the calorific values.

<sup>a</sup>Jour. Am. Chem. Soc., vol. 21, p. 1130.

TABLE 2.—The coals of Table 1, showing moisture-free hydrogen and oxygen, fixed carbon in pure coal, hydrogen to oxygen, and volatile carbon to carbon ratios, "available" hydrogen, and variance from C: (O+ash) ratio and efficiency curve.

No.	Designation of coal.	N.	S.	H(-H <sub>2</sub> O).	C.	O(-H <sub>2</sub> O).	Ash.	H <sub>2</sub> O.*	C O+ash	Calo- ries.	Proximate.		Fixed carbon in pure coal.	Vol. C C	H O	Variance from curve (calories).	Avail- able H.
											Fixed carbon.	Volatile matter.					
1	Mass. 1.	1.40	0.58	4.05	40.78	18.87	20.74	13.60	0.79	4,055	18.72	46.94	28.51	54.09	21.5	+150	1.69
2	N. Dak. 1B.	.55	3.95	2.82	44.11	11.01	12.75	24.82	1.96	4,321	29.85	32.58	47.81	32.32	25.6	-26	1.44
2a	Mont. 3701.	.65	3.66	2.83	48.01	14.73	18.00	15.12	1.04	4,432	36.54	30.34	45.46	30.95	19.2	-128	.99
3	Wyo. 3094.	.85	.61	2.92	47.45	26.28	6.87	13.83	1.07	4,468	40.12	39.15	50.63	17.47	15.1	-162	1.50
3	N. Dak. 3.	1.39	1.32	2.91	48.45	11.40	8.88	26.64	1.08	4,498	27.92	36.56	43.30	11.45	25.7	+28	1.68
4	Ark. 10.	.91	1.65	3.47	48.51	14.36	12.97	19.13	1.09	4,714	32.54	35.36	47.92	32.92	24.2	-185	1.36
4a	Mont. 3816.	.65	1.55	2.95	48.55	12.78	9.41	24.11	1.11	4,522	15.80	50.68	23.77	67.46	23.1	-10	1.18
5	N. Dak. 2B.	.88	.71	3.13	50.79	15.62	6.10	22.77	1.21	4,922	35.72	34.41	50.95	29.67	20.6	+100	1.80
6	Fla. 1.	2.56	.49	4.59	51.18	22.31	5.68	13.19	1.28	4,961	24.30	56.83	29.95	52.52	29.9	+100	2.38
7	Tex. 1.	.95	1.04	4.08	52.06	13.40	14.85	13.40	1.29	5,199	23.00	42.75	40.41	44.29	29.9	+100	1.88
8	N. Dak. 1.	.72	2.02	3.51	52.66	13.45	12.24	15.42	1.31	5,084	33.61	38.73	46.47	36.17	26.1	-85	1.83
9	Wyo. 3.	1.40	2.85	3.63	49.59	9.42	17.20	12.58	1.31	5,108	30.48	43.46	41.22	42.03	25.2	-100	1.73
9a	Wyo. 3892.	.72	6.86	3.44	52.58	13.67	14.75	11.31	1.36	5,108	33.61	35.39	49.59	29.78	38.5	-10	2.45
10	Ind. T. 5.	1.22	4.06	3.54	52.39	7.30	25.75	5.74	1.37	5,201	37.05	31.46	54.07	29.28	48.5	-25	2.63
11	Cal. 1.	.73	3.40	4.32	52.83	12.37	17.29	9.05	1.41	5,275	34.23	39.43	46.47	35.20	34.9	-30	2.78
12	Mo. 7C.	.98	3.47	3.67	53.55	8.28	27.57	2.48	1.41	5,399	38.78	31.17	55.43	27.58	44.3	+95	2.64
12a	Wyo. 2326.	.88	4.78	4.00	52.53	12.72	17.35	7.74	1.42	5,261	36.95	37.96	49.33	29.66	31.5	+55	2.41
13	N. Dak. 2.	.91	1.63	3.75	55.16	16.11	6.71	16.73	1.46	5,273	39.49	37.10	51.56	28.40	53.7	-105	1.74
13	Hil. 2.	.78	4.30	3.98	54.06	7.61	24.16	5.31	1.48	5,471	36.24	38.12	54.27	33.29	43.6	+30	3.05
15	Mo. 7A.	1.01	3.46	3.83	54.30	7.65	22.35	7.41	1.48	5,503	38.12	32.12	54.27	29.79	50.1	+72	2.87
16	Mo. 3.	.92	4.13	3.91	54.79	7.45	23.30	5.51	1.56	5,506	39.11	32.08	54.93	28.61	52.5	+40	2.98
17	N. Mex. 2.	.98	1.30	4.15	56.71	10.51	19.22	8.13	1.57	5,668	37.83	34.82	52.07	33.29	43.6	+100	2.93
18	Wyo. 2.	.80	4.17	4.24	55.29	10.51	22.26	2.73	1.57	5,758	37.61	37.61	49.86	30.00	25.1	+206	2.06
19	Tex. 2.	1.06	.71	4.10	57.31	16.36	9.81	10.66	1.60	5,502	40.11	39.42	50.43	36.69	47.3	+158	2.99
20	Wyo. 2B.	.85	4.22	4.07	55.84	8.60	21.77	4.64	1.62	5,815	35.35	35.35	48.03	30.00	25.1	+105	2.99
21	Mexico 1.	.96	1.02	3.87	58.97	8.60	21.77	9.76	1.63	5,984	47.69	22.07	68.36	19.12	69.7	+255	3.18
22	Tex. 4.	.97	1.70	3.98	58.83	15.80	9.96	9.76	1.71	5,682	42.77	37.51	53.27	27.29	25.2	+200	2.00
23	Mo. 10.	.97	4.28	3.85	57.25	8.12	23.76	1.77	1.71	5,857	43.97	30.50	59.04	23.19	27.1	+100	2.84
24	Tex. 3.	1.18	1.30	4.04	58.43	14.88	10.30	9.88	1.72	5,715	43.65	36.17	54.68	25.29	47.4	+55	2.18
25	Wyo. 1.	.65	1.71	3.66	59.65	11.13	4.79	17.62	1.73	5,824	39.56	26.15	65.91	15.09	32.9	+6	2.27
26	Hil. 7A.	.99	4.63	3.98	57.43	7.96	18.22	6.80	1.78	5,863	38.16	36.82	50.89	33.55	50.0	+7	2.99
27	Tenn. 11.	1.13	.92	3.82	60.56	3.78	28.53	1.26	1.81	5,836	40.95	21.24	69.74	18.97	101.1	+53	3.35
28	Mo. 7B.	1.02	4.13	3.99	57.82	7.05	22.82	2.17	1.81	5,853	40.95	34.05	54.59	29.17	56.6	+92	3.21
28a	Colo. 3856.	1.35	.60	4.40	60.49	9.55	19.47	4.14	1.85	6,029	43.75	32.64	57.27	27.73	46.1	+35	2.68
29	Mont. 2.	1.14	.62	4.16	60.97	11.81	15.92	5.39	1.87	6,020	46.03	32.65	58.47	24.50	35.2	+12	2.83
30	W. Va. 24.	.66	.55	3.27	62.36	3.51	28.77	.52	1.90	6,002	58.60	12.11	82.87	6.02	93.2	+12	2.75
31	Mont. 1.	1.36	1.76	4.24	60.41	11.96	11.22	9.05	1.93	5,989	43.03	36.70	53.96	28.77	35.5	-	2.75

31a	Colo. 3729	1.30	4.62	61.17	10.57	15.08	6.76	1.93	6.089	44.45	33.71	56.87	27.33	43.7	65	3.30
32	Colo. 1	1.22	4.25	61.13	12.96	6.32	13.49	1.95	5.995	43.03	37.11	53.69	29.60	32.7	65	2.63
33	Ill. 29A	1.97	4.16	59.37	8.51	17.31	4.92	1.95	6.008	43.89	33.68	56.58	26.07	48.9	24	3.10
33a	N. Mex. 3311	1.51	4.52	60.32	12.73	10.14	8.86	1.96	5.994	43.13	37.87	53.25	28.50	35.5	57	2.93
34	Ind. 20	1.16	4.14	60.96	7.20	19.99	4.38	1.96	6.089	44.73	30.90	59.14	26.62	57.5	37	3.20
35	Ark. 9	1.28	3.47	62.49	4.71	25.90	1.11	1.97	6.067	57.64	15.35	79.97	7.76	73.7	5	2.88
36	Iowa 5	1.22	4.83	59.89	8.37	13.55	9.22	1.98	6.105	44.52	32.71	57.65	25.66	57.7	32	3.78
37	Mont. 3	1.09	4.24	62.32	12.34	13.82	5.63	2.00	6.126	47.15	33.40	58.33	24.34	34.4	35	2.70
38	Ill. 4	1.01	4.50	59.88	8.45	15.80	6.67	2.01	6.135	42.02	36.01	53.85	29.82	49.5	35	3.13
39	Ill. 27	1.17	4.09	61.79	8.39	11.83	11.40	2.03	6.106	44.30	32.45	57.72	28.30	48.4	10	3.01
39a	Wyo. 3699	1.09	4.27	62.05	15.59	5.77	10.12	2.04	6.039	47.55	36.59	56.51	23.37	31.7	90	2.32
39b	Wyo. 3780	1.73	4.41	60.53	14.55	6.05	10.12	2.04	6.040	48.13	35.70	57.41	20.49	37.4	90	2.79
40	Ind. 3	1.18	4.26	59.58	7.54	17.48	5.12	2.04	6.090	42.92	34.88	55.16	27.96	56.5	37	3.32
41	Wyo. 4	1.90	4.40	62.68	15.04	17.48	9.21	2.04	6.116	42.04	41.27	50.46	32.93	29.2	14	2.78
42	Mo. 1	1.08	4.68	62.32	8.40	17.48	9.21	2.06	6.110	41.78	35.31	54.20	30.22	54.1	36	3.25
43	Ill. 6	1.53	4.25	59.88	7.82	13.10	9.21	2.06	6.191	40.77	35.35	53.55	32.05	79.4	36	3.58
44	Ill. 6	1.23	4.45	60.00	5.35	20.38	5.13	2.09	6.199	47.46	32.68	59.22	21.50	44.7	25	3.11
44a	Mont. 3515	1.69	4.39	61.76	9.64	14.73	12.19	2.10	6.057	43.94	40.46	52.06	28.85	29.0	140	2.50
44b	Mont. 3515	1.03	3.81	62.51	7.44	19.82	1.93	2.11	6.184	51.44	26.81	65.74	17.71	51.1	100	2.88
46	Wash. 1	1.30	4.58	60.93	8.40	17.96	2.86	2.11	6.180	43.14	36.04	54.48	29.18	50.3	12	3.18
47	Ill. 21B	1.58	4.23	63.28	11.60	12.91	5.98	2.12	6.182	45.96	35.40	57.65	27.37	36.6	18	3.80
48	Iowa 2	1.24	4.25	62.74	13.44	9.95	7.05	2.12	6.226	47.60	35.40	56.36	24.13	31.7	24	2.98
49	Ill. 7B	1.03	4.19	62.84	9.69	12.35	8.52	2.12	6.278	46.95	32.18	59.33	25.29	43.2	76	2.98
50	Wash. 1B	1.29	4.30	60.71	7.37	16.99	4.25	2.14	6.227	41.75	37.02	53.00	30.85	59.3	7	3.45
51	Ind. 1	1.22	4.58	63.35	12.20	12.58	5.20	2.15	6.273	45.08	36.54	55.56	32.15	53.6	2	3.06
51a	Iowa 4	1.33	4.24	62.20	7.29	13.81	8.66	2.16	6.336	42.67	39.86	51.70	31.40	58.1	96	3.33
52	Iowa 4	1.94	4.46	61.25	17.01	5.56	7.06	2.17	6.401	43.44	43.94	49.71	30.95	28.0	145	2.64
52a	N. Mex. 3952	1.03	4.20	63.00	8.80	16.62	10.03	2.18	6.237	41.22	37.27	52.52	32.70	54.9	20	3.25
52b	Wyo. 2325	1.23	4.05	64.28	14.19	7.73	8.29	2.19	6.220	44.52	39.45	53.02	30.74	56.8	235	3.90
52c	Colo. 3463	1.16	4.40	63.43	13.60	6.49	9.87	2.19	6.198	46.97	36.67	56.16	25.95	50.2	50	2.28
53	Ill. 25B	1.12	4.41	60.96	8.42	14.24	5.79	2.19	6.337	43.18	36.79	53.99	29.17	52.4	65	3.06
53a	Wyo. 3917	1.56	4.19	63.57	17.32	3.80	8.70	2.20	6.310	48.44	39.05	55.36	23.80	24.2	30	2.02
54	Ill. 9C	1.95	4.06	62.23	8.41	17.71	2.25	2.21	6.273	47.09	32.95	58.83	24.33	48.3	10	3.01
55	Ill. 22A	1.06	4.58	60.94	8.41	13.63	6.39	2.22	6.267	41.89	37.89	52.51	27.94	28.6	18	3.12
55a	Wyo. 3698	1.88	4.38	63.81	15.34	2.84	11.71	2.23	6.153	45.98	39.47	53.81	31.33	51.6	43	2.46
56	Wyo. 4B	1.85	4.68	64.01	13.67	7.04	8.94	2.23	6.288	42.70	41.32	50.82	33.29	37.9	120	3.48
57	Ill. 29B	1.29	4.32	61.69	8.27	13.05	7.14	2.23	6.302	44.85	35.72	55.24	28.53	52.2	2	2.79
57a	Wyo. 3605	1.10	4.51	64.07	14.41	7.14	8.07	2.23	6.420	42.09	41.93	50.54	33.13	31.3	115	3.21
58	Ill. 6B	1.10	4.23	61.96	8.44	15.43	4.17	2.23	6.420	44.85	32.63	59.42	26.90	50.1	80	3.16
59	Ill. 29	1.08	4.30	61.67	9.11	13.55	5.58	2.24	6.393	45.14	35.73	55.82	22.80	47.2	1	3.25
60	Iowa 1	1.07	4.03	61.80	6.27	16.52	5.21	2.25	6.329	46.51	31.76	59.42	24.74	64.3	38	3.35
61	Ill. 1	1.07	4.25	62.01	8.28	13.72	6.28	2.25	6.300	41.08	38.92	51.85	33.73	53.0	38	3.25
62	Ill. 15	1.09	4.32	62.25	8.49	13.81	6.00	2.25	6.356	43.91	36.28	54.76	29.46	50.9	30	3.26

\* Moisture (H<sub>2</sub>O) is included as a separate percentage to conserve the "air-dried" basis of the analyses and calorific determinations.

c Car sample (in part).

d From shallow mine or country bank.

e Coals more or less weathered.

f Sample probably deteriorated.

TABLE 2.—The coals of Table 1, showing moisture-free hydrogen and oxygen, fixed carbon in pure coal, hydrogen to oxygen, and volatile carbon to carbon ratios; "available" hydrogen, and variance from C: (O+ash) ratio and efficiency curve—Continued.

No.	Designation of coal.	N.	S.	H (-H <sub>2</sub> O).	C.	O (-H <sub>2</sub> O).	Ash.	H <sub>2</sub> O*.	C O+ash	Calo- ries.	Proximate. Fixed carbon, volatile matter.	Fixed carbon in pure coal.	Vol. C C	H O	Variance from curve (calories).	Avail- able H.
62a	Utah 4013.....	1.30	4.7	4.14	64.88	15.56	8.53	5.12	2.26	6,293	53.21	61.62	17.99	Per cent. 26.6	-30	2.20
63	Iowa 3.....	.93	6.83	4.43	60.62	7.14	15.53	4.52	2.27	6,309	38.99	48.77	35.68	62.0	+2	3.54
64	N. Mex. 1.....	1.05	6.4	4.52	64.34	11.49	7.10	10.86	2.28	6,353	46.90	57.16	27.10	39.3	+25	3.08
65	Kans. 2B.....	1.11	5.03	4.09	62.65	3.79	21.82	1.51	2.32	6,329	48.42	63.15	22.71	107.9	+37	3.62
66	Ind. 14.....	1.97	5.34	4.05	62.05	8.04	14.75	4.34	2.33	6,430	42.64	52.70	31.28	56.1	+45	3.50
67	Colo. 3498.....	1.26	7.76	4.40	64.95	14.03	7.42	7.18	2.33	6,446	46.50	54.45	28.41	81.4	+58	2.65
68a	Ind. 13.....	1.87	3.37	4.40	63.39	7.54	12.81	6.42	2.34	6,414	42.02	52.81	33.71	58.3	+14	3.46
68	Ind. 4.....	1.24	2.59	4.26	64.10	8.18	16.05	3.58	2.35	6,426	47.41	58.99	26.04	52.0	+26	3.24
69	Ind. 30.....	1.03	4.80	4.56	62.60	9.29	14.45	3.27	2.35	6,510	43.18	52.48	31.02	49.1	+105	3.40
70	Ill. 21.....	1.22	1.54	4.30	64.76	10.24	12.20	5.74	2.36	6,514	47.17	57.48	27.16	41.9	+109	3.02
71	Ill. 22B.....	1.00	4.90	4.29	62.99	8.40	16.36	2.06	2.36	6,327	44.81	59.43	28.86	37.9	+32	3.24
72	Ind. T. 4.....	1.38	4.02	4.29	63.21	8.79	13.40	4.91	2.38	6,376	47.17	57.48	30.54	51.1	-97	3.19
73	Ill. 31.....	1.47	6.66	4.47	65.05	12.07	6.28	10.00	2.38	6,312	50.98	60.89	21.63	37.0	-112	2.96
73a	Colo. 3545.....	1.14	4.05	4.41	65.51	8.49	14.67	6.17	2.39	6,394	45.94	56.33	27.62	51.9	+40	3.35
73b	Colo. 3490.....	1.13	8.89	4.44	65.51	11.44	10.42	3.77	2.39	6,532	47.13	56.50	27.75	38.8	+95	3.01
73c	Mont. 4115.....	.92	2.43	3.92	65.17	9.37	14.49	3.70	2.40	6,348	52.68	64.39	19.16	41.8	-95	2.75
74	Wyo. 2283.....	1.03	5.58	4.25	65.76	16.07	14.49	8.88	2.40	6,410	47.20	53.83	28.22	26.5	-58	2.24
75	Ind. 7.....	1.25	4.60	4.42	62.97	7.01	13.51	7.36	2.41	6,446	46.80	53.28	32.09	63.0	-40	3.54
75a	Ind. 7.....	.94	3.85	4.21	63.70	8.33	11.61	6.66	2.44	6,419	47.29	57.76	26.53	50.5	-4	3.17
75b	Colo. 3462.....	1.22	1.14	4.57	65.33	12.71	6.37	8.91	2.48	6,534	49.22	60.53	27.62	35.9	+55	2.98
76	Ind. 14.....	1.40	5.4	4.25	66.12	14.00	4.78	6.13	2.51	6,496	44.31	57.03	25.56	30.4	+25	2.50
77	Ill. 14.....	1.19	4.52	4.43	63.85	8.08	12.05	5.24	2.51	6,519	37.70	54.03	30.60	54.8	-105	3.29
77	Ohio 3.....	1.28	1.88	4.36	64.85	8.57	13.43	4.73	2.54	6,548	46.68	57.13	28.86	50.8	-11	3.29
78	Ill. 12.....	1.14	3.61	4.33	63.14	7.87	18.27	2.23	2.54	6,600	48.34	59.91	25.46	55.0	+47	3.72
79	Kans. 2.....	1.19	4.63	4.49	64.22	4.71	18.27	5.91	2.58	6,555	47.63	59.91	24.56	91.5	+25	3.71
80	Ind. 6.....	1.04	4.43	4.63	64.49	6.25	11.80	4.99	2.59	6,538	42.71	52.87	33.49	71.8	-52	3.55
81	Ill. 9A.....	1.19	4.02	4.65	66.81	12.90	6.82	9.80	2.59	6,579	43.99	52.86	31.79	53.7	+25	3.71
81a	Ariz. 4112.....	1.21	4.02	4.37	65.02	8.12	13.85	3.41	2.60	6,723	39.02	52.86	27.73	36.1	+133	3.05
82	Ill. 26.....	1.10	5.55	4.85	66.95	14.29	3.52	8.68	2.61	6,456	46.49	54.58	29.84	53.8	-150	3.04
83	Wyo. 6.....	1.10	5.4	4.85	67.48	10.31	10.92	5.27	2.62	6,625	40.95	55.14	30.56	33.9	+20	2.66
84	Ill. 19E.....	1.53	1.60	3.95	67.35	14.63	3.02	8.67	2.63	6,654	41.31	62.74	22.08	38.3	+40	2.37
85	Colo. 3703.....	1.12	1.74	4.24	67.42	14.89	14.84	2.29	2.63	6,660	31.23	56.61	25.85	28.4	+40	3.13
86	Ala. 2B.....	1.52	1.14	4.21	67.35	8.65	14.84	2.29	2.63	6,660	31.23	62.31	23.33	48.6	+40	3.13
86	N. Mex. 3A.....	1.15	4.50	4.67	67.54	7.31	17.01	1.48	2.64	6,742	48.80	59.87	27.75	63.9	+122	3.52
87	Ind. 16.....	1.23	4.50	4.50	64.82	7.88	12.49	4.68	2.64	6,623	44.24	53.41	31.75	57.1	-4	3.57
88	Kans. 6.....	1.14	4.00	4.50	65.65	5.89	16.92	2.09	2.66	6,663	42.89	60.54	25.32	73.2	+50	3.92
88	Tenn. 9B.....	1.26	4.78	4.56	67.76	5.09	19.47	1.03	2.66	6,693	52.89	66.53	21.95	89.6	+50	3.92
90	Mo. 5.....	1.02	5.68	4.50	64.52	7.20	15.37	1.71	2.69	6,614	44.95	54.21	30.33	62.5	-1	3.60



TABLE 2.—The coals of Table 1, showing moisture-free hydrogen and oxygen; fixed carbon in pure coal; hydrogen to oxygen, and volatile carbon to carbon ratios; "available" hydrogen; and variance from C: (O+ash) ratio and efficiency curve.—Continued.

No.	Designation of coal.	N.	S.	H (-H <sub>2</sub> O).	C.	O (-H <sub>2</sub> O).	Ash.	H <sub>2</sub> O*.	C O+ash	Calo- ries.	Proximate.		Fixed carbon in pure coal.	Vol. C C	H O	Variance from curve (calories).	Avail- able H.
											Fixed carbon.	Volatile matter.					
135	Kv. 9B.	1.39	3.10	4.64	68.35	8.11	10.50	3.91	3.09	6,985	51.49	34.10	60.15	24.67	Per ct.	63	3.63
135a	Ill. 19D.	1.56	6.64	4.08	70.55	9.67	9.63	3.87	3.10	6,897	55.19	31.31	63.80	21.77	42.2	+ 30	2.87
136	Ind. 15.	1.56	1.00	4.56	69.89	8.09	8.97	4.83	3.11	6,979	50.82	35.28	59.03	27.29	56.7	+ 44	3.55
136a	Colo. 3640.	1.50	4.49	4.80	70.32	12.24	5.74	5.21	3.12	6,908	55.69	33.36	62.54	20.80	60.0	+ 27	3.27
137	Ind. T. 3.	1.07	3.67	4.47	68.18	7.45	11.28	3.46	3.12	6,927	47.82	37.45	56.78	29.86	69.2	+ 11	3.54
138	Kans. 4.	1.07	8.33	4.64	65.02	4.74	12.63	3.57	3.16	6,854	46.80	37.00	54.79	28.02	97.9	-107	4.05
139	Ill. 16.	1.56	1.19	4.43	70.14	8.07	10.00	4.61	3.16	6,921	54.05	31.35	63.29	22.94	54.9	+ 41	3.42
140	Va. 5A.	1.69	1.66	3.52	72.23	3.37	18.80	4.73	3.17	6,929	69.92	51.98	86.89	3.20	104.4	+ 33	3.10
141	N. Mex. 5.	1.19	7.70	4.64	70.65	6.40	14.78	1.34	3.17	7,065	51.98	32.30	61.49	27.30	72.5	+ 95	3.84
142	Ind. 7.	1.09	4.34	4.79	67.99	7.04	9.55	5.50	3.17	6,920	44.99	39.96	52.86	33.83	68.0	+ 84	3.91
143	Kans. 1.	1.09	4.49	4.49	68.22	4.98	13.14	3.63	3.18	6,891	50.01	33.11	60.17	26.69	36.2	+ 30	3.87
144	Wyo. 5.	1.52	8.66	4.70	70.50	12.95	10.35	6.00	3.20	6,955	52.71	38.69	57.19	24.60	57.0	+ 12	3.50
145	Wyo. 5.	1.39	2.07	4.49	69.91	7.88	11.15	3.11	3.21	6,978	52.71	38.69	61.48	24.60	57.0	+ 21	3.72
146	Ill. 11.	1.29	1.99	4.71	69.85	7.94	10.35	3.87	3.21	7,011	50.05	35.73	58.35	28.34	59.3	+ 85	3.26
146a	Colo. 3946.	1.63	1.71	4.85	70.39	12.70	5.48	4.24	3.22	7,075	53.04	37.24	58.75	24.65	58.2	+ 21	3.41
146b	Colo. 3586.	1.63	1.31	4.79	70.00	11.04	6.39	4.84	3.22	7,024	50.49	38.28	56.88	27.87	43.4	+ 25	3.41
146c	Wyo. 4302.	1.55	6.64	4.14	71.09	11.63	6.33	4.62	3.23	6,911	54.85	34.20	61.60	24.99	60.9	+ 88	2.69
147	Ill. 19B.	1.48	96.14	4.36	70.70	7.16	9.92	5.42	3.23	6,877	53.03	31.63	62.64	24.99	61.9	-123	3.47
147a	Colo. 3943.	1.60	1.14	4.88	70.20	11.80	6.07	4.31	3.23	7,072	51.93	37.69	57.95	26.03	40.9	+ 72	3.40
147b	Colo. 3773.	1.23	4.26	5.64	67.50	10.18	6.37	4.86	3.24	7,086	52.71	47.74	56.22	39.21	55.1	+ 75	4.37
147c	Ohio 7.	1.23	3.21	4.68	69.19	6.70	10.83	3.11	3.26	6,947	50.17	34.84	59.00	27.49	69.8	+ 73	3.84
149	Ind. 7B.	1.24	4.14	4.80	68.94	7.89	10.23	2.76	3.34	7,020	46.55	40.46	53.50	32.48	60.8	+ 45	3.48
149a	Colo. 3546.	1.60	4.74	4.77	71.03	10.28	6.09	5.49	3.37	7,069	54.10	34.32	61.19	23.86	46.4	+ 4	3.85
150	Tenn. 6.	1.32	4.55	4.55	72.14	5.62	14.86	1.36	3.38	7,159	55.69	28.43	66.30	22.80	81.4	+ 79	3.80
151	Tenn. 9A.	1.01	96.96	4.49	71.84	5.57	14.46	1.36	3.38	7,135	56.22	27.96	66.78	21.71	80.6	+ 47	3.30
152	R. I. 1.	1.17	0.71	64.64	69.07	2.62	19.45	3.42	3.41	6,229	75.11	5.02	93.73	1.98	24.4	-860	3.31
153	Ind. 10.	1.32	4.17	5.08	69.07	8.24	9.33	2.85	3.43	7,113	45.07	42.75	51.32	34.75	61.6	+ 3	4.05
154	Ohio 8.	1.35	2.97	4.86	70.18	8.68	8.76	3.19	3.46	7,055	48.26	39.79	54.81	25.76	56.6	+ 82	3.78
154a	Wyo. 3480.	1.23	95.95	4.95	71.24	11.89	3.71	5.45	3.48	7,199	52.89	37.95	58.22	31.31	56.6	+ 188	3.46
155	Pa. 13.	1.23	2.19	4.88	71.25	5.82	13.35	1.27	3.50	7,221	51.89	33.49	60.77	27.17	83.7	+ 71	3.88
156	Tenn. 1.	1.65	4.74	4.74	71.36	7.26	11.49	1.87	3.52	7,096	50.87	33.93	60.84	28.14	65.3	+ 65	3.47
157	Tenn. 3B.	1.25	4.42	4.68	69.59	14.41	13.07	1.36	3.52	7,122	50.06	35.51	58.50	26.90	101.6	+ 37	4.05
158	Tenn. 7A.	1.26	3.32	4.77	70.46	5.73	13.07	1.70	3.52	7,096	50.87	35.51	58.50	26.90	83.2	+ 40	3.88
159	Ala. 1.	1.26	4.79	4.79	72.16	6.46	12.64	1.56	3.53	7,201	49.79	37.19	57.24	31.05	74.1	+ 40	3.98
160	Ind. T. 2.	1.72	1.56	4.81	71.49	7.40	11.32	1.70	3.53	7,243	53.25	36.99	59.01	26.70	43.3	+ 65	3.39
160a	Colo. 3936.	1.40	4.76	4.76	72.92	5.03	6.95	2.81	3.55	7,341	68.01	16.40	66.57	6.73	79.9	+ 163	3.39
161	Gal. 1.	1.13	4.02	4.02	72.65	10.99	14.97	2.62	3.62	7,358	56.36	37.60	59.98	22.76	32.0	+ 145	2.84
161a	Wyo. 4323.	1.48	1.28	4.66	72.97	14.57	1.68	4.36	3.62	7,358	56.36	37.60	59.98	22.76	32.0	+ 145	2.84

162	Va. 5B.	74	70	74	33	51	47	45	65	112	71	00	11	00	86	50	4	48	151.4	-115
163	Pa. 3	80	77	75	33	23	33	2.08	3.68	6,920	7,112	71	00	7,277	59	60	1.18	115.7	312	+39
164	Tenn. 8A	80	45	75	21	45	16	1.05	3.68	7,920	7,112	71	00	7,277	59	60	1.18	115.7	312	+39
165	Ill. 3A	113	45	85	70	45	16	2.13	3.68	7,920	7,112	71	00	7,277	59	60	1.18	115.7	312	+39
166	Ala. 4	125	114	47	73	46	13	2.98	3.68	7,920	7,112	71	00	7,277	59	60	1.18	115.7	312	+39
166a	Colo. 3587	125	114	47	73	46	13	4.17	3.77	7,207	7,207	55	13	30	22	30	22	54.5	93.9	+4
167	Ohio 12B	125	114	47	73	46	13	1.69	3.77	7,207	7,207	55	13	30	22	30	22	24.56	55.0	+4
168	Ohio 10	125	114	47	73	46	13	2.24	3.77	7,207	7,207	55	13	30	22	30	22	29.57	67.3	+4
169	Pa. 6	127	118	49	72	47	15	2.27	3.77	7,207	7,207	55	13	30	22	30	22	29.57	67.3	+4
170	Ill. 11C	143	121	50	72	47	15	2.36	3.77	7,207	7,207	55	13	30	22	30	22	29.57	67.3	+4
171	Ohio 9A	122	116	49	72	47	15	2.36	3.77	7,207	7,207	55	13	30	22	30	22	29.57	67.3	+4
171a	Colo. 3938	122	116	49	72	47	15	2.36	3.77	7,207	7,207	55	13	30	22	30	22	29.57	67.3	+4
171b	Colo. 3585	122	116	49	72	47	15	2.36	3.77	7,207	7,207	55	13	30	22	30	22	29.57	67.3	+4
171c	Colo. 3932	122	116	49	72	47	15	2.36	3.77	7,207	7,207	55	13	30	22	30	22	29.57	67.3	+4
172	Ohio 12A	123	118	49	72	47	15	2.47	3.82	7,343	7,343	55	49	40	35	40	35	24.67	54.1	+20
173	Kans. 5	123	118	49	72	47	15	1.58	3.85	7,343	7,343	55	49	40	35	40	35	24.67	54.1	+20
173a	W. Va. 3570	118	113	48	71	46	14	1.84	3.85	7,343	7,343	55	49	40	35	40	35	24.67	54.1	+20
173b	W. Va. 22B	118	113	48	71	46	14	2.90	3.85	7,343	7,343	55	49	40	35	40	35	24.67	54.1	+20
174	Tenn. 4	163	153	52	83	62	31	1.77	3.96	7,465	7,465	57	82	33	91	60	71	24.99	45.5	+5
174a	Colo. 4036	163	153	52	83	62	31	1.77	3.96	7,465	7,465	57	82	33	91	60	71	24.99	45.5	+5
175	W. Va. 22B	118	113	48	71	46	14	2.90	3.96	7,465	7,465	57	82	33	91	60	71	24.99	45.5	+5
175a	Colo. 4225	118	113	48	71	46	14	1.71	3.96	7,465	7,465	57	82	33	91	60	71	24.99	45.5	+5
176	Pa. 17	144	133	53	84	73	42	1.54	4.08	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
176a	Colo. 7573	144	133	53	84	73	42	1.54	4.08	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
177	W. Va. 25	143	132	52	83	72	41	1.95	4.08	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
178	Ohio 4	166	155	54	85	74	41	1.95	4.08	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
178a	Colo. 4036	166	155	54	85	74	41	1.95	4.08	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
179	Ark. 8	133	122	52	83	72	41	2.16	4.17	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
179a	Colo. 4048	133	122	52	83	72	41	2.16	4.17	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
180	Ky. 8	186	175	62	91	80	69	3.10	4.18	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
181	Ark. 12	123	112	51	80	69	58	1.92	4.24	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
182	Ark. 1	147	136	62	91	80	69	1.17	4.30	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
183	Ohio 5	145	134	62	91	80	69	1.90	4.31	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
184	Ohio 5	143	132	61	90	79	68	2.34	4.31	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
185	Tenn. 5	169	158	67	96	85	74	1.35	4.37	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
186	Tenn. 3	117	106	56	85	74	63	2.52	4.37	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
187	Tenn. 3	117	106	56	85	74	63	2.52	4.37	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
188	Ohio 12C	188	177	67	96	85	74	1.47	4.43	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
189	Pa. 22	188	177	67	96	85	74	1.47	4.43	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
190	Md. 12	132	121	60	89	78	67	1.03	4.47	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
191	Pa. 12	146	135	64	93	82	71	1.03	4.47	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
192	Pa. 7A. 22A	152	141	69	98	87	76	2.51	4.48	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
193	Pa. 7A. 22A	152	141	69	98	87	76	2.51	4.48	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
194	Tenn. 9C	125	114	47	73	46	13	1.92	4.48	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
195	Ark. 3	125	114	47	73	46	13	1.92	4.48	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
196	Pa. 21	125	114	47	73	46	13	1.92	4.48	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
197	Pa. 4	125	114	47	73	46	13	1.92	4.48	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
198	W. Va. 3	146	135	64	93	82	71	1.29	4.48	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
199	W. Va. 23B	146	135	64	93	82	71	1.29	4.48	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1
200	W. Va. 5	143	132	61	90	79	68	1.99	4.65	7,589	7,589	59	61	39	50	58	41	30.67	58.5	+1

\* Moisture (H<sub>2</sub>O) is included as a separate percentage to conserve the "air-dried" basis of the analyses and calorific determinations.

<sup>a</sup> Coals more or less weathered.

<sup>b</sup> From shallow mine or country bank.

TABLE 2.—The coals of Table 1, showing moisture-free hydrogen and oxygen, fixed carbon in pure coal, fixed carbon in pure coal, hydrogen to oxygen, and volatile carbon to carbon ratios, "available" hydrogen, and variance from C: (O+ash) ratio and efficiency curve—Continued.

No.	Designation of coal.	N.	S.	H (-H <sub>2</sub> O).	C.	O (-H <sub>2</sub> O).	Ash.	H <sub>2</sub> O.*	C O+ash	Calo- ries.	Proximate.		Fixed carbon in pure coal.	Vol. C C	H O	Variance from curve (calories).	Avail- able H.
											Fixed carbon.	Volatile matter.					
201	W. Va. 16.	1.53	1.26	4.66	76.09	6.48	8.76	1.22	4.66	7,609	56.96	33.06	63.27	25.14	71.9	-15	3.85
202	Pa. 19.	1.42	1.08	4.81	76.25	6.86	8.57	1.01	4.67	7,752	57.81	32.57	63.98	24.13	70.1	+115	3.95
203	Pa. 4.	1.75	5.58	5.46	72.45	5.46	5.23	5.39	4.68	7,516	44.47	44.91	49.76	28.62	94.6	-17	4.49
204	Ky. 1B.	1.73	1.16	4.89	75.89	6.22	8.54	1.57	4.69	7,623	55.14	34.75	61.43	27.34	78.6	-17	4.41
205	W. Va. 2.	1.37	3.50	4.93	74.44	6.40	7.90	1.46	4.70	7,700	50.50	40.14	55.71	32.16	77.0	+157	4.13
206	Ark. 7A.	1.32	2.12	3.38	76.37	3.38	12.29	1.60	4.71	7,413	70.00	17.11	80.36	32.16	101.0	-230	3.50
207	Tenn. 2.	1.81	1.01	4.98	75.97	7.25	7.03	1.95	4.76	7,690	54.05	36.97	59.38	29.53	68.7	-25	4.07
208	W. Va. 4B.	1.60	4.37	76.72	4.48	4.48	10.38	1.35	4.77	7,626	60.88	27.39	68.93	20.65	97.5	-38	3.81
208a	Wyo. 4303	1.31	1.94	4.81	76.84	10.81	3.23	2.06	4.84	7,812	57.53	35.17	60.74	25.13	44.5	+163	3.46
208b	Colo. 4010.	1.56	1.45	5.03	77.05	8.38	6.32	1.21	4.88	7,860	59.43	30.90	65.79	25.63	60.0	+126	3.98
209	W. Va. 23A.	1.69	1.10	4.76	76.64	6.14	8.48	1.19	4.88	7,613	59.43	30.90	65.79	22.46	77.5	-83	3.99
210	Va. 6.	1.45	1.24	4.95	76.57	6.50	7.71	1.58	4.90	7,643	55.50	35.20	61.18	27.51	76.2	+57	4.14
210a	Ala. 3745.	1.13	1.27	4.82	77.40	4.87	10.30	1.67	4.96	7,757	64.77	24.28	72.39	16.11	89.7	+48	3.76
211	Ark. 5.	1.88	1.33	5.06	77.05	7.71	8.38	1.58	4.96	7,764	59.11	32.92	64.23	23.63	61.8	-270	3.84
211a	Colo. 3552.	1.39	2.01	3.60	77.29	2.22	12.21	1.28	5.04	7,443	73.69	12.83	85.18	4.65	162.1	-92	3.55
212	Pa. 9.	1.29	2.09	3.94	77.42	8.05	5.31	2.07	5.04	7,676	54.22	38.40	58.54	29.24	62.9	-62	4.05
213	W. Va. II.	1.04	1.53	3.94	79.12	3.14	11.63	1.50	5.09	7,761	70.12	17.75	79.91	9.42	125.5	-92	3.56
214	Pa. II.	1.45	1.19	4.94	77.52	3.07	7.33	1.36	5.17	7,699	57.03	34.28	62.46	26.24	77.1	-70	4.14
215	W. Va. 15.	1.56	2.56	4.91	76.52	4.82	8.63	1.12	5.29	7,743	52.60	37.55	58.28	31.26	101.9	-92	4.20
215a	Wyo. 4299.	1.85	1.70	5.32	78.19	9.05	3.48	2.40	5.37	7,855	61.87	36.79	68.91	26.08	98.8	+48	4.09
216	W. Va. 4.	1.50	1.90	4.74	78.21	5.24	8.43	1.98	5.37	7,855	51.75	33.64	63.59	25.32	72.5	+55	3.91
216a	Ala. 3771.	1.53	1.44	4.94	78.67	6.81	6.81	1.86	5.53	7,901	58.54	35.81	61.42	29.30	63.9	+31	4.04
217	Va. 4.	1.35	1.44	4.86	78.56	7.60	4.42	2.40	5.59	7,890	57.02	35.81	61.42	29.30	63.9	+31	4.04
218	W. Va. 2B.	1.45	1.90	4.92	78.51	6.41	6.37	1.94	5.60	7,869	55.36	36.92	60.00	29.31	79.7	+9	4.31
219	W. Va. I.	1.55	1.28	5.11	78.31	6.41	6.25	1.33	5.64	7,877	57.04	35.38	61.71	27.02	78.0	+9	4.31
220	W. Va. 10.	1.29	1.23	4.99	78.16	6.40	6.25	1.70	5.66	7,877	57.04	35.38	61.71	27.02	78.0	+9	4.31
221	Va. 1.	1.27	1.41	4.96	78.47	7.50	4.85	1.70	5.66	7,870	57.66	35.49	61.70	26.52	66.4	-64	4.04
222	W. Va. 20.	1.38	1.58	4.98	78.39	5.01	3.20	1.60	5.68	7,812	58.17	32.89	63.88	25.79	100.6	-17	4.34
223	W. Va. 8.	1.37	1.38	4.98	78.75	8.17	7.35	1.60	5.71	7,863	58.92	32.12	64.72	25.18	99.4	-17	4.35
224	W. Va. 6.	1.48	1.58	5.02	78.94	8.17	2.82	2.99	5.78	7,807	56.88	37.31	60.39	27.95	61.4	+95	4.00
225	Pa. 5.	1.41	1.49	4.40	78.94	4.42	8.33	1.00	5.78	7,903	62.68	34.83	62.31	26.90	81.8	+5	3.85
226	Pa. 5.	1.55	1.55	5.04	78.78	6.16	6.11	1.47	5.83	7,864	57.59	34.83	62.31	26.90	81.8	+5	3.85
227	Pa. 16.	1.33	1.05	4.42	79.00	5.05	8.19	1.36	5.83	7,812	68.78	22.67	75.21	12.94	87.5	-36	4.29
227a	Ala. 3769.	1.10	1.05	4.83	79.00	7.39	4.05	1.02	5.87	7,964	59.87	33.48	63.87	24.37	65.4	+52	4.27
228	Pa. 20.	1.16	2.96	4.50	78.23	1.80	10.93	1.62	5.90	7,992	72.17	10.86	81.41	24.37	280.0	-224	3.91
229	Ky. 1.	1.85	1.24	5.15	78.31	7.09	4.44	1.82	5.91	7,955	57.08	36.36	60.96	27.11	72.6	+35	4.26

230	Pa. 15B	1.18	4.06	4.24	77.52	1.97	10.55	48	5.98	7.781	70.49	18.48	79.23	9.07	215.2	-150	4.02
231	W. Va. 18	1.45	.68	4.77	79.65	6.95	5.92	1.28	6.01	7.963	59.03	33.77	63.61	23.88	76.3	+133	3.89
231a	Ala. 3744	1.33	.67	5.09	79.57	8.08	3.21	1.22	6.03	7.965	60.68	34.53	63.69	23.67	76.0	+177	3.99
231b	Calif. 4047	1.83	.59	4.57	79.77	3.91	8.64	1.70	6.03	7.977	69.07	24.53	76.74	13.47	166.9	+37	4.06
232	W. Va. 9	1.63	.80	4.93	79.67	5.30	6.79	1.01	6.03	7.984	69.67	23.53	68.01	21.02	89.9	+44	4.24
233	Ky. 5	1.63	.80	5.01	79.17	7.81	3.81	1.80	6.10	7.958	58.56	30.33	61.98	20.77	77.5	+8	3.83
233a	W. Va. 21	1.32	.63	5.04	80.23	6.90	6.85	1.89	6.28	7.915	66.39	27.16	70.85	28.75	91.9	+42	4.23
236	Ala. 6	1.46	1.00	4.75	80.63	5.15	6.36	.74	6.38	7.911	63.47	16.26	61.97	18.41	159.5	+230	4.10
237	Ark. 9	1.46	1.00	4.05	80.73	1.32	10.69	.94	6.89	7.936	71.46	18.12	69.77	7.96	238.8	-133	3.73
237a	Pa. 15	1.10	3.88	4.38	78.61	1.32	8.63	.88	6.89	7.885	74.69	16.10	82.74	7.49	107.5	-119	4.16
238	Pa. 18	1.23	1.86	4.92	80.74	2.08	6.38	2.05	6.81	7.826	74.69	16.10	82.74	7.49	107.5	-119	4.16
239	W. Va. 14	1.56	1.56	4.69	80.73	6.30	3.38	.89	7.01	7.690	64.97	30.00	68.23	20.02	78.1	+232	3.61
239a	Ark. 3174	1.49	2.86	3.80	80.48	1.32	8.31	.89	7.13	7.934	76.38	14.97	83.89	6.65	230.0	-147	3.67
239b	Pa. 67	1.21	2.23	3.90	81.10	2.42	9.27	.89	7.32	8.234	73.61	20.54	78.18	6.82	104.0	+156	3.65
240	Pa. 7	1.20	1.20	4.30	82.39	5.19	5.09	.74	7.68	8.086	73.83	18.14	81.36	10.88	161.1	-49	4.11
241	Md. 9	1.06	1.68	4.46	82.39	2.77	7.29	.74	7.69	7.948	76.66	14.29	84.29	6.58	253.2	-185	4.07
242	Ind. T. 9	1.68	1.24	4.28	82.06	1.69	8.41	1.28	7.78	8.180	60.32	34.56	63.58	26.32	93.7	+38	4.51
242a	Ala. 3770	1.55	.49	3.20	82.06	5.95	3.84	1.28	7.83	8.220	62.19	32.36	65.77	24.31	96.1	+4	3.94
243	Pa. 8	1.63	.68	4.30	83.11	5.14	4.58	.87	8.10	8.170	75.22	17.32	81.28	9.49	149.8	+39	3.94
244	Pa. 8	1.29	.87	5.02	82.65	4.87	4.01	1.17	8.32	8.234	62.39	31.87	66.39	23.83	103.1	+4	4.41
245	W. Va. 13	1.26	.81	4.29	83.63	2.48	6.95	.63	8.38	8.185	74.38	18.05	80.47	11.06	173.0	+19	3.98
246	W. Va. 12A	1.34	.69	4.83	83.18	2.48	6.95	.63	8.38	8.185	74.38	18.05	80.47	10.58	295.7	+4	4.64
247	W. Va. 12	1.53	.85	4.63	83.62	3.66	5.09	.64	8.68	8.300	72.53	21.74	76.94	13.26	126.5	+4	4.17
248	W. Va. C	1.70	.66	4.63	83.62	3.66	5.09	.64	8.97	8.301	72.53	21.74	76.94	13.26	126.5	+4	4.17
249	W. Va. 19	1.01	.91	4.35	83.56	3.53	3.13	.68	9.01	8.203	70.91	23.28	75.23	15.14	129.7	+30	4.14
250	W. Va. 10	1.07	.57	4.51	85.91	2.66	4.63	.65	11.78	8.439	75.92	18.80	80.15	11.63	169.6	+30	4.18

\*Moisture (H<sub>2</sub>O) is included as a separate percentage to conserve the "air-dried" basis of the analyses and calorific determinations.  
 a Coals more or less weathered.

The slight recalculation of the analyses shown in this table offers the data necessary for the observation of the relative amounts of hydrogen and oxygen assumed to be in actual hydrocarbon compounds; and these, as well as the relative amounts of volatile carbon (total carbon less fixed carbon) are made available for comparison as ratios, H:O and VC:C, without further departure from the air-dried basis of the analysis. The fixed carbon of the proximate analysis not only shows marked local variations, but also is subject to considerable error in the process of determination. By combining the volatile carbon in ratio with the more constant and accurately determined total carbon, following the method employed by Professor Parr,<sup>a</sup> the fixed carbon error of the proximate analysis is minimized.

The criteria for the study of the composition of the fuels are advantageously supplemented by the calculation of the fixed carbon in "pure coal" (ash and water free) by the method recommended by Professor Grout.<sup>b</sup> By this method the fixed carbon in "pure coal" is determined by dividing the fixed carbon by the sum of the fixed carbon and "volatile combustible matter" as given in the proximate analysis. For use in comparison the variance of the ascertained calorific value from the curve value is noted for each coal; also the amount of available hydrogen.

#### COMPENSATED CALORIFIC VALUES.

It may be of interest to remark at this point that the C:(O+ash) ratios, if recalculated on the moisture-free basis of the oxygen as given in Table 2, fluctuate widely from the ratios in Table 1; but if the calories also be recalculated to compensate for the eliminated water weight—that is, if the ascertained calories on an air-dried basis be divided by 100 minus moisture in air-dried coal—we shall have corresponding new theoretical efficiencies in larger denomination. On referring the new ratio to its serial position higher in the scale of the old ratios it will generally be found that the compensated calorific value will again fall near its proper, though entirely new and different, position in the succession of calorific values. For example, the C:(O+ash) ratio of No. 25, when computed from the moisture-free oxygen of Table 2, will be found to be 3.23 instead of 1.73; and the air-dried efficiency of 5,753 calories is changed to 6,989 calories when compensated for a loss of 17.69 per cent weight of moisture. Inspection of the ratio series in Table 2, or of the curve, shows that a coal having a ratio of 3.23 should have an efficiency of approximately 7,000 calories.

A few other examples, taken at random, of coals having high moisture may be presented. No. 64 of the tables, a New Mexico Cretaceous coal, whose ratio is 2.28, its efficiency error being very small, has a moisture of 10.86 per cent. On the moisture-free basis the

<sup>a</sup>Bull. Geol. Survey Illinois No. 3, 1906, p. 31.

<sup>b</sup>Econ. Geology, vol. 2, 1907, p. 240.

ratio of this coal becomes 3.46 and the compensated efficiency 7,127; by reference to the curve or to the proper point in the succession of the ratios in Table 2 it will be seen that the calorific value of a coal having a ratio of 3.46 should be about 7,137. In other words, this coal, whose curve error was +6 on the air-dried basis, appears to have an error of +10 when projected on the moisture-free basis among the high-grade bituminous coals of Tennessee, Ohio, and Pennsylvania. Another coal having relatively high moisture content in its air-dried condition is No. 144 of the tables. This coal from Wyoming has a moisture content of 6 per cent and a ratio of 3.20, its efficiency error being -30; on the moisture-free basis the ratio of this coal becomes 4.23, the compensated calories becoming 7,399. Passing up the scale of the ratios it appears that a coal having a ratio of 4.23 should have a calorific value of a little less than 7,430; so that this coal which had a deficiency of 30 on the air-dried basis, when projected as moisture-free with a higher ratio, shows a deficiency of about 80 calories in its new position on the curve. No. 203, a Paleozoic coal from Missouri, with moisture 5.39 and a ratio of 4.68, has an error of -120 calories, probably due to the very high sulphur. The moisture-free ratio of this coal is 6.78, the compensated calories being 7,944. The calorific value for a coal having a ratio of 6.78 should, according to the curve, be not far from 8,030; so that the error when this coal is projected on the moisture-free basis to a position among the highest grade semi-bituminous coals becomes -85 calories instead of -120, as developed on the air-dried basis. Again, No. 32, a Laramie coal from Lafayette, Colo., has a moisture of 13.39 and a ratio of 1.95, its variance from the curve being -45 calories; the ratio on the moisture-free basis for this coal is 3.17, the recalculated efficiency being 6,929. Passing down the columns to No. 142 we find that the efficiency for a coal with a ratio of 3.17 should be 6,970, showing an error of -41; in other words, this coal, which had an error of -45 in its normal air-dried condition, has almost the identical error when recalculated to eliminate the moisture and referred to a new position very much higher in the curve.

#### VALUE OF MOISTURE-FREE DATA.

Comparisons of this kind are of value chiefly as indicating the consistent progression of the ratios and the stability of the curve as applied both to moisture-laden and to moisture-free coals. The dry coals fall in the same scale as the air-dried and with nearly equal precision. For the entire series of coals in the table the average total for the carbon, oxygen, and ash is about 91.82. It is perhaps permissible to interpret this agreement of the moisture-free ratios and compensated values as indicating approximate equivalence in anti-calorific value for the oxygen of the moisture and the oxygen of the coal itself, as well as for the ash.

An inspection of Table 2 shows that in many coals of the same ratio and of nearly equal efficiency there are striking differences in the amounts of fixed carbon (in pure coal), and a wide range in the H:O ratios, the latter being also apparent with respect to coals with the same percentage of fixed carbon. Similarly a less noticeable fluctuation is seen in the relations of the VC:C ratios both in coals of the same efficiency and in those of equal fixed carbon. The variations thus disclosed appear, in some instances, to explain the departures of the ascertained efficiencies from the calorific values indicated by the ratio curve.

The data in this table offer not only a better opportunity to study the relative values of oxygen and ash, since the oxygen is restricted to that assumed to belong to the coal itself, but also a basis for considering the comparative anticalorific importance of the oxygen of the moisture in the air-dried samples tested. The latter question becomes, under the circumstances, largely a matter of observation of the effects of the varying percentages of oxygen, ash, and moisture, in a miscellaneous and somewhat heterogeneous aggregate of coals.

The relative values of these impurities may be more precisely estimated if the coals are grouped as to kinds and districts, rather than merely by the ratio sequence, and each kind is studied by itself. Possibly, also, new and slightly modified curves will be found in groups of this sort.

#### RELATIVE NEGATIVE VALUE OF ASH AND OXYGEN.

The question whether oxygen or ash is negatively more potent is difficult to determine from the comparison of so wide a range in kind, condition, and age of coals. The difficulty is further complicated and rendered more delicate by the fact that so many of the errors or variances from the curve lie within the range of error in the work of the calorimeter, the average ratio-curve error for the total number of analyses being very much less than 1 per cent of the average calorific value. The question is therefore, for the present, left somewhat in doubt. From study of the tables, however, I am inclined to believe that the oxygen is possibly of slightly greater anticalorific importance in the lowest grade of bituminous and the subordinate group of coals, while in the higher bituminous and the semibituminous fuels the ash is probably of greater negative value. From a casual glance it would appear that in the air-dried samples the greater anticalorific value lay in the oxygen. But the possibility that many of these coals have taken up oxygen under exposure to air or weathering conditions enjoins caution in forming conclusions; for, as I shall indicate later, the oxidized coals are generally characterized by deficiencies, as compared to the curve, in calorific value. On the other

hand, the arrangement of the coals is such that the slightly greater available hydrogen prevalent in the coals with high ash (on account of their generally higher class) may be regarded as counterbalancing a small margin of the disadvantage attributable to the ash, thus appearing to indicate for the ash a slightly greater anticalorific value. However, the number of instances of parity of coals with alternating percentages of the two impurities, in which no unusual available hydrogen accompanies the high ash, is so great as to preclude any important difference of negative value in favor of the ash. But it will be observed in passing down the columns of the table that coals with high hydrogen are usually accompanied also by high sulphur, whose diluent influence in the analysis tends to neutralize the effect of the high available hydrogen. Thus it becomes more readily practicable in general to treat the hydrogen as constant, and so to ignore it, along with the nitrogen and sulphur, in forecasting the calorific values of the fuels by means only of the  $C:(O + \text{ash})$  ratios.

On the whole, the calorimetric tests make it evident that high oxygen (with its usually slightly lower available hydrogen concomitant) and high ash (in most cases accompanied by slightly higher available hydrogen) counterbalance, so that practically, taking coals as they come, the calorific values of two coals in which the two great impurities alternate, carbon being constant, are almost exactly equal. The facts presented in the tables show plainly and conclusively why the Paleozoic coals of the Eastern Interior basin can not possess the efficiency of Appalachian standard coals of the same ash percentage; and why the very low-ash, but high-oxygen samples of low-class, subbituminous, and lignitic coals of the Cretaceous or Tertiary exhibit a calorific efficiency no greater than that of high-class Paleozoic coals having contrastingly high ash and correspondingly low oxygen, if the total carbon is the same.

It will later be shown that some of the maximum variations in the available hydrogen are responsible for a number of the larger variances from the ratio curve in Tables 1 and 2. The latter are not, however, sufficiently numerous or large to require a coefficient for compensation.

It is probable that for a group of cannel and bogheads in which the hydrogen is excessively high a higher special cannel curve will be found desirable. The construction of such a curve based on the ascertained component ratios and efficiencies will be much simpler, and perhaps in general more reliable, than a coefficient for the abnormally high hydrogen of this group.

#### RELATIVE EFFECT OF THE OXYGEN OF MOISTURE.

The obstacles to distinguishing between the negative values of the oxygen of the coal proper and the oxygen of moisture, in the calo-

rimeter results, are largely the same as those affecting the discrimination between the relative values of ash and oxygen. In fact, the effect of moisture on the standing of the coals as determined by the C : (O + ash) ratios is generally so little as to excite surprise. For example, the efficiency shown in the test of No. 31, a Fort Union coal from Deer Lodge, Mont., which has 9.05 per cent moisture, or No. 32, the Laramie coal at Lafayette, Colo., with 13.49 per cent of moisture, differs less than 1 per cent from the efficiency of No. 30, the Pocahontas bone at Gary, W. Va., which has but 0.52 per cent moisture. Other coals, such as Nos. 71, 72, and 72a, afford similar striking contrasts, the calorific values being so little affected and so regularly conformable to the curve as to make it clear that no great difference can exist between the negative values of the oxygen of moisture and that combined in the coal.

In connection with this question of the relative values of the two oxygens attention should be called to the approximate coincidence and complete conformity of the ratios of the moisture-free coals and of their respective compensated calorific values with the curve of the air-dried coals, as noted on page 34.

A review of the efficiency variations in Table 2 tends to show slightly more frequent calorific deficiencies in coals having abnormally high moisture. But, on the other hand, allowance must be made for the fact that most of the samples very high in moisture are low in the scale of coal formation, and consequently most susceptible to deterioration on exposure to atmospheric oxygen. There is no doubt in my mind that many such deficiency variances are due to this cause. Furthermore, so many of the instances of calorific deficiency which might perhaps correctly be ascribed to high moisture are attendant on unusual deficiencies in the available hydrogen, that at the end one is left uncertain whether, so far as may be judged by the behavior of the air-dried samples in the calorimeter, the moisture oxygen in general differs much from other oxygen in its harmful effect. This does not, of course, preclude the recognition of a difference under practical boiler-grate conditions.

The varying capacity of coals of the same age and district, under apparently the same conditions as to progressive metamorphism, to hold water seems to depend largely both on the character of the original constituent organic matter and on the conditions governing the first or biochemical stage of coal formation.

Since coals with high oxygen and low ash have the same calorific values as others in which the terms are reversed, if the other percentages are constant, it becomes evident that, in general, the carbon-oxygen ratio of the coal (ash free, or ash constant) corresponds fairly closely to the rank of the coal in efficiency. The same ratio also indicates, for coal of the same origin, its progress in the scale of coal transformation.

## ESTIMATE OF THE EMPIRICAL ANTICALORIFIC VALUE OF OXYGEN.

## NEGATIVE VALUE OF OXYGEN AND ASH.

In the preceding pages it has been shown that, in general, throughout a miscellaneous collection of coals of all grades, the heating value of the fuel is roughly indicated by the amount of the total carbon as compared to the sum of the oxygen and ash. Also that, so far as concerns the calorific efficiencies of the coals, alternating amounts of oxygen and ash essentially offset each other, providing the total carbon be constant, though strictly speaking a slight excess of negative potency appears to lie in the ash. On the whole, however, in view of the tendency of two of the assumed constants, sulphur and hydrogen, to compensate each other, as will be pointed out in the next section, we may conclude that, from the practical standpoint, oxygen and ash may be regarded, according to the calorimetric tests, as essentially interchangeable.

## APPLICATION OF THE CURVE.

The curve platted from the C:(O+ash) ratios and the calorific efficiencies provides an indirect method of ascertaining the average amounts of calorific change corresponding to any given ratio change, for different parts of the curve. For any one length or section of the curve the amount of this calorific change may be taken as a scale of approximately equal units, by which any fractional ratio change may be measured. Hence it is not difficult roughly to estimate the anticalorific values of 1 per cent added to or subtracted from the oxygen or ash in a coal analysis.

Inspection of the curve, as provisionally drawn, shows the following approximate values of curve segments covering changes of 0.05 and 0.01 in the ratios (horizontal component) at a number of points:

*Calorific changes corresponding to ratio changes of 0.05 and 0.01 at stated points in curve.*

Part of curve.	Ratio change 0.05.	Ratio change 0.01.
<i>Ratio.</i>	<i>Calories.</i>	<i>Calories.</i>
1.00	115.0	23.0
1.50	80.0	16.0
2.00	50.0	10.0
2.50	40.0	8.0
3.00	35.0	7.0
3.50	28.0	5.6
4.00	22.0	4.4
4.50	19.0	3.8
5.00	13.3	2.6
5.50	10.0	2.0
6.00	8.0	1.6

## FLUCTUATION IN EFFECTS OF CHANGES.

The practical application of these units at once discloses wide fluctuations in the relative effects of changes of 1 per cent in the joint impurity. These are due (1) to the constantly changing elements upon which the ratios are based, and (2) to the marked difference between the ratios as a curve component, with constantly progressive dividends and divisors, and the component of the efficiencies. The essential result is an increase in the negative value of the impurities in passing from one part of the curve to another, as the following figures show:

At ratio 1.00 the value of 1 per cent of added oxygen or ash is about 47.5 calories; at ratio 1.50 the value of 1 per cent of added or subtracted oxygen or ash averages approximately 64.5 calories; at 2.00 the average approximates 65.4 calories; at 2.50 it approximates 78 calories; at 3.00 it approximates 92 calories, the effect becoming more strongly marked in subtraction; at 3.50 it averages about 97 calories; at 4.00 the variation between the added and the subtracted 1 per cent is slightly greater, the average of both at that point being about 93.9; the decline is still more marked at 5.00, where 1 per cent of the joint impurity is valued at nearly 82.2 calories, while at 5.50 its effect is about 77 calories; and at 6.00 it falls to about 72 calories. At this point (ratio 6.00) deduction of 1 per cent of the impurity amounts to an addition of about 77.6 calories, while addition of the same percentage causes a change of about 69 calories. These values are based in each case on the average of the differences between the ratios in Table 1 and those obtained by adding 1 per cent and by subtracting 1 per cent from the total oxygen plus ash.

## ESTIMATE APPLIED TO THE ANALYSES.

A clearer idea of the application of this indirect method may easily be gained by practical experimentation with the analyses in the table, the ratio changes resulting from increase or diminution of the impurities being compared with the calorific differences indicated by the corresponding changes in the curve. For example, No. 145 of Table 1 has a ratio of 3.21, the corresponding efficiency being 6,990 calories. The addition of 3 per cent of oxygen or ash to this coal produces a coal whose C:(O + ash) ratio will be 2.82. The calorific value of a compensated coal having this ratio will be found to be about 6,750 calories, showing a difference of about 240 calories on account of the addition of 3 per cent of oxygen, the impairment averaging, therefore, about 80 calories to each 1 per cent of added impurity. If, on the contrary, we subtract 3 per cent from the oxygen or ash of the coal in No. 145, we shall have a coal with a ratio of 3.72, whose efficiency, according to the curve, will be about 7,260 calories,

an increase of approximately 270 calories, as the result of deducting 3 per cent of impurity; that is, 90 calories to each 1 per cent. Or, to take another example at random, No. 183 in Table 1, with a ratio of 4.31, has a calorific curve value of 7,515. The addition of 3 per cent of oxygen or ash produces a coal with a ratio of 3.67, whose efficiency will be approximately 7,238 calories, a calorific difference of 277, being approximately 92 calories to each added 1 per cent of the joint impurity. Contrariwise, the subtraction of 3 per cent in the analysis of No. 183 defines a coal having a ratio of 5.21, according to which the calorific value of the coal will be 7,780, showing a difference of approximately 265 calories resulting from the difference in the impurity, or 88 calories as the average advantage derived from the elimination of 1 per cent of the impurity.

Tests of this kind may be applied to all of the coals in the table. They are, however, inaccurate and of little value, though interesting. The fluctuations are very wide and vary from the amounts calculated from the value of the combustible displaced or concentrated by the addition or subtraction, respectively, of the inert impurity.

#### CAUSES OF VARIANCE FROM THE CURVE.

##### GENERAL STATEMENT.

The causes of the wider fluctuations of the ascertained efficiencies from the C:(O + ash) ratio and efficiency curve appear in most cases to lie in the percentages of those elements that have been ignored as negligible constants, hydrogen, sulphur, and nitrogen. Besides these we have, also, among the data of the analysis the less definite, though no less absolute, effects of (1) oxidation by weathering and (2) the devolatilization incidental to anthracitization. There are, however, other causes which seem incapable of detection from the mere ultimate analyses. Although of subordinate importance, these will first be considered.

##### CAUSES NOT SHOWN BY ULTIMATE ANALYSES.

First are the differences in the hydrocarbon compounds entering into the substance of the coal. These compounds, whose number and structure appear still to be largely unknown, presumably vary in stability, in quantity, and more or less in calorific values. Some of these differences are probably due to the nature of the original ingredients. The bogheads, for example, are described as largely composed of the remains of gelatinous algæ, which appear to have exercised a selective attraction for certain bituminous compounds, and which are excessively rich in volatile combustible having an illuminating value far above that derived from ordinary gas coals. Pyropissite, which is largely composed of resins, is an extreme example in this category.

The obviously abundant resin in some of our Cretaceous low-grade<sup>a</sup> bituminous and subbituminous coals and lignites doubtless contributes to the calorific excess which attends many of the unweathered samples. A number of these coals figure among the extreme excess variances among the efficiencies marked "L" to the left in the curve diagram, Plate I.

Another, possibly the principal, of the intangible causes not revealed by the analyses is the error in oxygen determination in the process of making the ultimate analysis. Since the oxygen is the residual of the analysis, ascertained by subtracting from a total of 100 per cent the sum of the percentages of the other elements, it is evident that it contains the residual error which may possibly be cumulative. Among the lower ratios a slight error in oxygen determination does not cause a very marked effect on the calorific variance, but in the higher grade coals a fraction of 1 per cent may make a considerable difference in the ratios, and a consequent erroneous indication of the efficiency. In a coal having a ratio of 2.00 an error of about 1 per cent of oxygen in the analyses will amount to a curve difference of about 63 calories. It is possible that the surprisingly low oxygen of several of the semibituminous coals<sup>b</sup> may in part be due to error in its determination.

An important source of error in oxygen determinations is connected with the presence of pyrite in the coals, for the production of sulphur dioxide causes an oxygen deficiency equal to three-eighths of the sulphur in the pyrite. The residual error (oxygen) of the analysis is also affected by the reduction of iron carbonate when that is present in the coal, the results being too high carbon and oxygen and too low ash. Small errors in oxygen calculations are also due to the recognized tendency in high-ash coals of the aluminous silts to hold back hydrogen and of siliceous sediments to withhold oxygen. The relatively few cases in which the marked variances are not fairly well explained by these or other causes, and in particular the very small average error of the efficiency curve, indicate a high standard of accuracy in the coal analyses on which this report is based.

As a third cause of variance not visible in the analyses is the oxygen taken up on exposure to the air or weathering, which constitutes a serious cause of variance on the side of deficiency. This matter will be again referred to (p. 63) in connection with the subject of the weathering of coals.

#### CAUSES RECOGNIZABLE IN ANALYSES.

The causes of variance that may, frequently at least, be recognized in the analyses will now be considered.

---

<sup>a</sup> By low grade is meant only less advanced in the process of coal formation.

<sup>b</sup> Nos. 228, 230, and 237.

## VARYING AVAILABLE HYDROGEN.

In Table 2 the proportions of hydrogen are shown both by means of its ratios with the oxygen in moisture-free coal, and as "available" hydrogen  $\left( H - \frac{O}{8} \right)$ . As might be expected, a number of the large errors seem to be explained by the relatively very large or very small percentage of hydrogen. Yet the evidence is not free from conflict, since in numerous analyses a high available hydrogen is shown without any corresponding error of excess calories; in others calorific excess attends a relatively low hydrogen. As coals in which the excess of calories would seem to be due to high hydrogen, citation may be made of Nos. 7, 21, 33, 36, 43, 52a, 86, 126, 168, 208b, and 247. Compare also Nos. 23, 38, 51, 53, 79, and 130. Several of the coals cited, however, are very low in sulphur, which, by reducing the amount of the negligible constants, enlarges the space for the other elements, especially carbon, and so promotes a higher efficiency for the fuel. There are on the other hand but few samples in which the lack of hydrogen seems clearly accountable for deficiency of calories. Probably of this sort are Nos. 19, 106, 112, 135a, 144, and 246. The low curve efficiencies of Nos. 163, 181, 190, 206, 211, and 236 are also possibly due to low hydrogen, though in these coals (marked "S" in Pl. I) which are undergoing anthracitization the volatile carbon likewise is very low; and since, in some of the advanced coals, an abnormally low volatile carbon appears to be a cause of calorific deficiency, it is possible that most of the coals last cited may be impaired by loss of volatile carbon as well as of hydrogen.<sup>a</sup> Outside of the semianthracites and more advanced semibituminous coals there do not seem to be many coals in the tables whose lack of calories is possibly traceable to low hydrogen. In Nos. 84, 93, 110a, 171c, and 196, the calories are high in spite of the low available hydrogen; while in No. 2b there is no available hydrogen at all, but on the contrary a deficiency of 0.37, yet the efficiency-curve error is but 150 calories. High efficiency with a relatively low available hydrogen is a common characteristic of the unweathered younger and less altered coals, in which the diluent sulphur is low. It is to be remembered that the efficiencies and errors here discussed relate to the ratio curve, and not to those calculated from Du Long's formula.

The number of coals in which a relatively high available hydrogen or H:O ratio is attended by a calorific deficiency, instead of excess, is surprisingly large. Examples are Nos. 27, 48, 56, 105, 138, 203, 215, 228, 237, and 238. (See also Nos. 40, 74, 76, 153, 158, 162, 164, 178, 185, 197, and 215.) Several of these coals have high sulphur, whose double effect is not fully overcome by the relatively high

<sup>a</sup> The relative values of both VC:C and H:O in the coals are better shown in Plate III than in Table 2.

hydrogen, as will presently be illustrated. Samples Nos. 228, 237, and 238 have abnormally low volatile carbon and very low oxygen; to the former the deficiency is probably due.

On the whole it may be said that while high available hydrogen tends to cause curve variances on the side of excess, there are comparatively few coals in which its effects are not so far neutralized by a high sulphur content, or (in case of very low sulphur) by an enlarged proportion of carbon or, perhaps, by a very high ash (Nos. 27 and 65), as to reduce the excess error to less than 100 calories. There appear to be 10 coals whose excess error of over 100 calories seems more or less distinctly due to the high available hydrogen. For the cannel-boghead group, whose hydrogen is characteristically greatly in excess, a higher curve should be drawn. The average total hydrogen in the 319 air-dried samples in Table 1 is 4.92 per cent.

#### SULPHUR.

In many respects sulphur is the most important of the neglected elements affecting the accuracy of the ratio-efficiency curve. Although the errors on account of this ingredient are generally slight, usually less than 1 per cent of the calorific value, its effect is no doubt relatively important in many cases.

In combustion the heat values of sulphur are generally recognized as depending on the state or condition in which it occurs. As free sulphur it is comparatively harmless and may exert its full theoretical calorific efficiency; in pyrite, marcasite, or other sulphides, its heat contribution is greatly lessened by the fact of combination, and also differs with the surrounding conditions; in sulphates, whether infiltrative, interstitial, or in the form of scales in the joints and cleavage planes of the fuel, it is a dead load to be borne at the expense of the other fuel elements. Unfortunately information as to the state of the sulphur in the samples tested and analyzed is unavailable for this report;<sup>a</sup> so that I am obliged to ignore the differences in the effects of the different kinds, and regard only the apparent influence in general and as a whole when the sulphur is in large or exceptionally small percentages.

Since the efficiency of the coals is very closely controlled, as has been shown, by the balance between the carbon and the two chief anticalorific elements, oxygen and ash, the sulphur, as well as the nitrogen and hydrogen, has in the preceding pages been treated as constant. But as a matter of fact, while the hydrogen and nitrogen appear to be constant in kind, differing only in quantity, the sulphur differs greatly both in quantity and in kind or effect. In the series of analyses shown in the tables the sulphur ranges, on the air-dried

<sup>a</sup> In most of the high-sulphur coals of the Eastern Interior basin the sulphur is probably chiefly in the form of sulphides.

basis, from a minimum of 0.22 per cent in No. 52b from Wyoming, to a maximum of 8.33 per cent in No. 138 from Kansas. Its average percentage in the 319 coals is 2.13.

Since sulphur even in its best condition has a smaller calorific value than carbon, it is plain that any unusually high percentage of it, unless compensated by increased available hydrogen, another of the constants, virtually dilutes the combustible of the coal and causes a falling off in its efficiency. Therefore a comparison of the analyses in the tables with reference to sulphur is necessarily chiefly confined, since we are not cognizant of the state of the sulphur in each sample, to the diluent effect in some of the coals of an abnormal proportion of this inferior combustible, and the effect of comparatively low sulphur in others. Accordingly, the practical and main purpose of the study is to observe the amount of the error or variance from the ratio-efficiency curve in consequence of unusual fluctuations in the sulphur percentages. As examples in which deficiencies in ascertained calorific value, as compared with the curve indications, are probably due to unusually high sulphur, may be cited Nos. 48, 65, 76, 80, 94, 96, 102, 138, 157, 185, 230, and 237 in the table. The errors in most of these cases are, however, small. The diluent effect of a difference in sulphur may in many coals be roughly approximated by rating the unit sulphur effect at the difference between its theoretical value (2,250) according to Du Long's formula and the calorific value of the unit of the rest of the coal which it partly displaces. The effect of the available hydrogen variation may be calculated at 34,460 according to Du Long's formula.

In passing down the columns it will be noted that as a rule the coals that are high in sulphur are also relatively high in hydrogen, the highest percentages of the former being usually attended by the greatest excesses of the latter.<sup>a</sup> The general result is the neutralization of the bad sulphur effect by the high hydrogen. In many cases the effect is converted from a deficiency to a small excess. As illustrating analyses in which the sulphur effect is not fully neutralized, comparison may be made of Nos. 9, 11, 16, 28, 40, 48, 55, 58, 63, 73, 74, 92, 105, 113, 138, 142, 143, 164, 178, and 203. Some of these are coals with the highest available hydrogen. Two of the most striking are No. 138 from Kansas and No. 203 from Missouri. Other instances of complete neutralization are Nos. 14, 20, 23, 33, 36, 38, 43, 48, 53, 69, 66, 79, 82, 98, 99, 147b, 153, 167, 168, 172, and 205. On the other hand, it will be noted that the coals with very low sulphur are more often accompanied by a low available hydrogen.<sup>b</sup> Some of the larger efficiency errors on the side of excess are coincident with the exceptional cases of very low sulphur and unusually high hydrogen. Examples are Nos. 21, 52a, 81a, 86, 93, 100, 118, 126, 128, 141, and 161a;

<sup>a</sup> Examples are Nos. 14, 20, 23, 40, 42-44, 45, 48, 49, 65, 66, 79, 82, 147-149, 153, 185, 187, 203, and 205.

<sup>b</sup> This applies to the Cretaceous and Tertiary coals in the tables.

also Nos. 31a, 134, 134a, 171a, 173b, and 179a. These fall for the most part among the Cretaceous coals, and their superior efficiency is probably connected with the high content of resin.

The review of the analyses with respect to sulphur shows, in general, that except among the fuels approaching anthracitization the coals with highest sulphur usually have the highest available hydrogen, those with lowest sulphur being usually relatively low in hydrogen; and accordingly that in most cases the effect of an excess of sulphur is nearly counterbalanced by the presence of an excess of hydrogen. Conversely, the effects of unusual proportions of hydrogen are, in general, largely neutralized by a parallel variation in the sulphur contents of the coal. These facts explain, in most cases, the smallness of the ratio-efficiency curve errors in the presence of the greater variations of the available hydrogen. The mutually neutralizing action of the sulphur and hydrogen is the main circumstance making it so readily practicable to treat these elements as negligible in forecasting the efficiency of the coal solely on the basis of the carbon, oxygen, and ash. It should be noted that compensating the oxygen for loss with sulphur of pyrite (see p. 42) would by lowering the C:(O + ash) ratio tend to reduce the prevailing errors of deficiency in high-sulphur coals, while slightly reducing the available hydrogen.

#### NITROGEN.

Of this, the third and last of the neglected constants, I have not attempted a careful study with reference to error influence. From a casual inspection of the tables I am inclined to regard it as largely eliminated from the peats at an early date in the dynamo-chemical process, the remainder being, perhaps, mechanically retained in a free state, or in an unknown state of combination in the more advanced coals. It seems to be practically passive, and of so little range in amount as usually to produce no marked effect as a diluent. Its average percentage in Table 1 is 1.21. The study of the effect of nitrogen on the calorific values requires a series of analyses including larger groups of peats and of the succeeding low grades of coals.

#### ANTHRACITIZATION.

Both the greatest individual error and the greatest average variance from the curve are found among the highest of the semibituminous coals, which are undergoing anthracitization or in the anthracitic group itself. A glance at the percentages of fixed carbon in pure coal in Table 2 shows that nearly all the coals that have a fixed carbon of 79 or more are deficient in calories unless they have a high volatile carbon (see the VC:C ratios). The maximum variance among the 312 coals of the table is in the anthracite culm at Scranton, which shows a deficiency of 312 calories from the curve. In many of these

coals the deficiency is probably due to loss of hydrogen, as shown in the available hydrogen column of the table.

Of the 18 coals with as much as 79 per cent fixed carbon and a volatile carbon ratio of 9.25 or less, only 2 show excess errors. These 18 coals (excluding the Rhode Island semigraphite, which is not a fuel) are here grouped for better comparison:

*Variance from curve efficiency of coals high in fixed carbon and low in volatile carbon.*

No.	Locality.	Variance from curve.	Fixed carbon in pure coal.	Ratio VC to C.	Available hydrogen.	Sulphur.
		<i>Calories.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
163	Scranton, Pa. ....	-312	91.09	1.13	2.30	0.77
179	Spadra, Ark. ....	-214	87.01	2.93	3.01	2.14
140	Blacksburg, Va. ....	-33	86.89	3.20	3.10	.66
162	.....do.....	-115	86.50	4.48	3.49	.70
211	Coal Hill, Ark. ....	-270	85.18	4.65	3.50	2.01
242	Panama District, Ind. T. ....	-185	84.29	6.58	4.07	1.24
239b	Johnstown, Pa. ....	-147	83.89	5.82	3.67	2.29
239a	Paris, Ark. ....	-252	83.34	6.65	3.61	2.85
30	Gary, W. Va. ....	+12	82.87	6.02	2.83	.55
238	Lloydell, Pa. ....	-115	82.27	7.49	4.16	1.55
236	Bonanza, Ark. ....	-250	81.92	7.96	3.73	1.90
228	Seward, Pa. ....	-224	81.41	7.74	4.28	2.96
190	Georges Creek, Md. ....	-106	80.94	9.02	3.42	1.51
161	Menlo, Ga. ....	+163	80.57	6.73	3.39	1.31
181	Arkansas ....	-215	80.45	9.15	3.26	1.68
206	Midland, Ark. ....	-230	80.36	7.64	3.50	2.12
237	Wehrum, Pa. ....	-133	79.77	9.11	4.20	3.88
230	.....do.....	-150	79.23	9.07	4.02	4.06

The average error for the 8 semianthracites, with fixed carbon of 83 per cent or more in pure coal, is 191 calories. The average error for the 10 highest-grade semibituminous, having a fixed carbon of over 79 per cent and a VC:C ratio (per cent) of 9.25 or less, is 158 calories. If this list of 18 coals be excluded from the table list the average error of the ratio curve is but 60.09 calories.

Other high-grade semianthracites which show calorific deficiency incidental to loss of volatile are the following:

*Variance from curve efficiency of coals high in fixed carbon.*

No.	Locality.	Variance from curve.	Fixed carbon in pure coal.	Ratio VC to C.	Available hydrogen.	Sulphur.
		<i>Calories.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
212	Kimmelfton, Pa. ....	-92	79.91	9.42	3.55	2.09
123	Huntington, Ark. ....	-100	79.66	9.40	3.36	1.14
182	.....do.....	-60	79.25	10.00	3.41	1.27

The last sample has a higher volatile carbon. The VC:C ratios are better studied in Plate III, in which the coals are arranged in the order of their fixed carbon in pure coal (ash and moisture free).

On the other hand, among these coals approaching devolatilization it is interesting to note signs that a relatively large proportion of carbon in the remaining volatile is favorable to a higher efficiency. For

illustration: The coal at Sun, W. Va. (No. 240), with a relatively high volatile carbon (VC:C=10.68 per cent) shows an excess of about 136 calories over the curve, though its available hydrogen, 3.65, is 0.45 below that of most of the coals near by in the series.<sup>a</sup> Relatively high volatile carbon probably assisted low sulphur in Nos. 213, 196, and 70, among others. Contrariwise, in Nos. 162, 228, 237, and 238 low efficiencies accompany unusual diminution of the volatile carbon, in spite of the fact that the available hydrogen is fully up to or above the normal in these coals. Possibly sulphur may have exercised a depreciating influence in Nos. 228 and 237.

These observations seem to indicate that although the calorific values in the lower grades of coals do not seem affected by the relative amount of fixed carbon, too great a loss of volatile carbon impairs the efficiency of the fuel.

The range of error in the determination of the fixed carbon in a coal forbids basing too confident conclusions on a limited number of observations.

#### WEATHERING.

The changes of coal under exposure or weathering are indicated in the analyses by reduced H:O ratios; by reduced available hydrogen; and in many cases by reduced volatile carbon ratios. Illustrations will be given later (p. 63) of these changes, invariably showing calorific deficiencies except in the high grades of coal. As a matter of fact weathering can in most cases be detected by the changes in the oxygen-hydrogen relations and by the marked calorific deficiencies.

### QUANTITATIVE RELATION OF OXYGEN TO COKING.

#### SUPPOSED ALGAL INGREDIENTS IN COALS.

#### SOURCE AND CHEMICAL EFFECTS.

As stated in the introduction to this paper, one of the purposes of this comparative study was to ascertain the testimony of the ultimate chemical analyses as to the validity of a previously conceived working hypothesis in explanation of the coking property of coals. A few words will outline the basis of this hypothesis:

The brilliant investigations carried on by Renault<sup>b</sup> and Bertrand<sup>c</sup> as to the microscopical structure of a considerable number of bog-heads and oil shales of various continents and geologic ages show that these rocks owe their peculiar physical and chemical characters (which include a relatively high percentage of volatile matter, a

<sup>a</sup> The estimate of calorific value calculated from the chemical analysis of this coal was 312 calories less than the ascertained efficiency. See Prof. Paper U. S. Geol. Survey No. 48, 1906, p. 255.

<sup>b</sup> Renault, B., *Les micro-organismes des combustibles fossiles*, St. Etienne, 1903.

<sup>c</sup> Bull. Soc. d'hist. nat. Autun, vol. 9, 1897, p. 193; Trav. et mém. de l'Univ. de Lille, vol. 4, No. 21, 1898; Compt. rend. 8me sess. Cong. géol. internat., 1901, p. 453.

generally high illuminating value, etc.) primarily to the presence of immense numbers of supposed gelatinous algæ which in these coals seem to have exercised a selective attraction for certain bituminous compounds. Algal matter in smaller proportions, and consequently with less distinct resultant characteristics in the coal, is found also in the "cannel-bogheads" and some of the "boghead-cannels." The conditions of accumulation and deposition attending the origin of many other coals were doubtless favorable for the mingling of algæ and different animal remains in varying quantities with the débris of higher plant types; though their preservation, at least in optically recognizable form, is most improbable in any but the rarest instances. Yet it is more than probable that the substances of these lower organisms, whether completely macerated and disorganized or not, contributed as ingredients to the mass of coal-forming material. It is therefore reasonable to admit that though not optically discernible now, or though all their original structure is obliterated, they have probably exerted some influence on the character and quality of the final converted organic residuum.

It is not important to discuss in this place either the source proposed by the French paleobotanists for the bituminous "enrichment" of the coal or the time of the bituminization, though, for my part, I am disposed to regard the enriching bitumen as derived from the decay of associated animal organisms, as well as from the putrefaction products of great quantities of the gelatinous algæ themselves. The relatively increasing importance of the bituminous matter in the more mature, older, or more altered condition of the fuel is due, I believe, to concentration as the result of devolatilization and reduction of the coal by the dynamochemical process, the larger part of the concentration being the result of loss of oxygen, which is in larger proportion at the outset. The oxygen loss is disproportionately great as compared to that of the hydrogen. The liquid putrefaction products of the algæ must almost certainly have entered into the groundmass of the coal and participated in the infiltration of the immersed structural vestiges of higher and more enduring types of vegetation. The progressive deoxygenation of the organic matter effects a concentration of the bituminous compounds in the body of the organic material which is undergoing the processes of coal formation; that is, it accomplishes bituminization. However, the important point, so far as we are at present concerned, is the connection, as described by the distinguished French paleobotanists and later virtually corroborated by Potonié,<sup>a</sup> of these gelatinous ("sapropelic" of Potonié) elements with a highly bituminous quality of the fuel.

---

<sup>a</sup> Jahrb. K. preuss. Landesanstalt u. Bergakad., vol. 25, 1907, pp. 342-368.

## CHARACTERISTICS OF ALGAL COALS.

We have next to note the following circumstances: (1) It will be seen on consulting the ultimate analyses published by the French paleobotanists that these algal (gelosic or sapropelic) coals are relatively high in hydrogen and low in oxygen, as is to be expected of coals that are tinged with the character of bitumen; (2) I have observed that those fuels, especially if Paleozoic and consequently more altered, are apt to fuse and even to swell on burning.

## POSSIBLE CONNECTION WITH COKING QUALITY.

Now, these qualities, fusibility and swelling, concurrent with bituminization, which appear generally to characterize fuels known to contain recognizable quantities of gelatinous micro-algæ, are also necessary to the coking quality in coals. It is permissible, therefore, to inquire whether the coking property may not be due, at least among coals relatively low in fixed carbon, to some unascertained but not improbable proportion of gelatinous algal (sapropelic) matter entering into the original ingredient mass from which the coal was formed, and either directly or indirectly imparting to it this fusibility and tendency to swell.

Micro-algal ingredients, sometimes forming layers of considerable thickness, are recognized in peats, and their presence, occasionally in great numbers, has already been noted in a number of remarkable brown coals which have not been altered so far as to preclude satisfactory microscopic examination. Yet the detection by means of the microscope of such minute and delicate organisms as the algæ described from some of the bogheads and cannels, even if vestiges happened to be preserved, in coals so highly changed by the dynamo-chemical process as the coking coals, is a matter so difficult as perhaps to justify consideration as improbable. Being apparently barred at present from satisfactorily determining their presence by direct mechanical means, we are therefore left to search the evidence of the chemical analyses.

Not only does it appear that among coals of the same degree of progressive devolatilization those with the greatest amount of recognizable micro-algæ show hydrogen and oxygen most nearly in the proportions shown in bitumen, but in general it also seems, conversely, that those normally sedimented coals whose ultimate analyses approach most nearly to that of bitumen bear the more distinct microscopical evidence of the presence of the algæ. The coals whose large volatile combustible matter contains relatively the highest hydrogen and the lowest oxygen, thus approaching nearest the bitumen analyses, are those in which the organic remains described as micro-algæ are most predominant and often best preserved.

Of the following analyses No. 1<sup>a</sup> represents the Torbane Hill bog-head; No. 2,<sup>a</sup> the Kerosene shale (Permian) of New South Wales; No. 3,<sup>b</sup> a hard pitch; No. 4,<sup>b</sup> "pitch E," used in briquetting tests.

*Analyses of algal coals approaching bitumen and of pitches.*

No.	S.	H.	C.	O+N.	Ash.	Moisture.
1	.....	8.50	65.44	3.44	22.62	.....
2	.....	9.63	76.61	2.87	10.64	.....
3	0.88	4.56	90.34	3.06	1.16	0.33
4	.66	4.22	91.30	2.99	.83	1.02

The tentative inference that sapropelic matter and the bituminous concentration<sup>c</sup> have a direct connection in these high-volatile coals is, I believe, quite justified.

If the inference is correct that in the high volatile coals high bituminization (concentration of bituminous substance) and gelatinous algal (or sapropelic) ingredient elements go together, and if the observation of the connection between the presence of the latter (and consequent bituminization) with the tendency of the coal to fuse and swell is well founded, it seems probable that such coals of high bituminization will contain algal elements and (what is more important) fuse on burning in the mass. In other words, we may conclude that high volatile coals whose analyses show sufficiently high bituminization will coke by the ordinary process. The degree of bituminization in these coals is indicated by the relative excess of hydrogen as compared with the diminished oxygen in dry coal. It is expressed by the ratio H:O.

#### HYDROGEN-OXYGEN RATIOS OF COKING COALS.

##### DESCRIPTION OF DIAGRAM IN PLATE III.

The test of this working hypothesis lies in the examination of the H:O ratios, dry-coal basis, of the coals with reference to the known behavior of the fuels in coking tests. The data essential to the study of the analyses for this purpose are set forth in diagram in Plate III. Sulphur is omitted from this diagram because it does not seem to influence the coking quality of the coal, though of course greatly affecting the quality of the coke from the metallurgic standpoint. Ash also is omitted as not essential to the comparison.

In this diagram all the coals are rearranged in the order of their fixed carbon percentages (F. C.) in pure coal, as given in Table 2, and

<sup>a</sup> Renault, B., *Les micro-organismes des combustibles fossiles*, p. 149.

<sup>b</sup> Prof. Paper U. S. Geol. Survey No. 48, pp. 266, 267.

<sup>c</sup> The gradual development of distinctness in the chemical resemblance to bitumen as progressive devolatilization eliminates more and more of the oxygen is essentially mere concentration. I therefore employ this term in place of enrichment, which suggests that bitumen has been brought in from some source entirely outside of the bed of coal.

with the same numbers. This order is chosen as conforming, to some extent, to the evolution of the coals. It is genetic in so far as it shows the progressive devolatilization of the coals—that is, the progress in their dynamochemical alteration or improvement.

In order to present the additional essential criteria in a simple and graphic arrangement for comparison, the hydrogen-oxygen ratios are platted as heavy continuous lines extending to the right, and the ratios of volatile carbon to carbon (VC:C) are platted as heavy broken lines extending to the left, from a point representing nearly complete devolatilization. In the figure columns both these ratios are expressed as percentages. For comparison with the H:O ratios the available hydrogen has also been platted as light broken lines extending to the right.

The annotations as to coking, at the right, are mainly those based on the tests by the United States Geological Survey and kindly furnished by Mr. J. S. Burrows, chief inspector. Information from other sources has been incorporated regarding some coals not tested for coke by the Survey.

#### INDICATIONS OF RATIO LIMITS.

The evidence of the hydrogen-oxygen ratios as to the coking quality of the coals needs no extended discussion. A review of the wide fluctuations in the H:O ratios, together with the annotations as to coking, strongly indicates, so far as the tests have been made or the information is at hand, that, below the highest of the semibituminous coals which are approaching anthracitization, those coals with a H:O ratio (percentage) of 59 or more, with but one or two exceptions, make coke by the ordinary commercial process. Nearly all those below 59 and above 55, so far as tested, make a coke, and among those ranging down to a ratio of 50 a large percentage coke, while one or two of the tested coals coke at a slightly lower ratio. It would seem, however, that the cokes made from those coals with a H:O ratio less than 55 are usually very poor and apt to be brittle and dark.

It appears, therefore, that among coals which are not too far devolatilized practically all that are sufficiently bituminized—that is, have a H:O ratio of 59 or over—are almost certain to possess the coking fusibility, and that coke of good quality may usually be expected from coal with a ratio as low as 55, while very poor results may be obtained when the ratio is as low as 50. The best cokes obtained by the ordinary process are made from coals having a ratio of 60 or over.<sup>a</sup> In the H:O ratios of Table 2 and Plate III no oxygen compensation is made for sulphur in pyrite.

<sup>a</sup> The coking tests made by the United States Geological Survey are based on the ordinary beehive-oven process.

No.	Lot.	Locality.	F. C. in pure coal.	* $\frac{H}{O}$	$\frac{H}{O}$ %*	VC %*	Remarks.	No.
4a	Mont. 3816	North-northeast of Glendive <sup>b</sup>	L23.77	1.36	23.1	67.46		4a
1	Mass. 1	Halifax	P23.51	1.69	21.5	54.09		1
6	Fla. 1	Orlando	P29.95	1.80	20.9	52.52		6
7	Tex. 1	Crockett	L40.41	2.38	29.9	44.29		7
9a	Wyo. 3892	Fall River <sup>a</sup>	S41.22	1.73	25.2	42.03		9a
3	N. Dak. 3	Wilton <sup>c</sup>	L43.30	1.50	25.7	41.15		3
147b	Cal. 3773	Stone Canyon	46.22	4.37	55.4	39.21	No coking test	147b
11	Cal. 1	Tesla	S46.47	2.78	34.9	35.20		11
8	N. Dak. 1	Lehigh	L46.47	1.83	26.1	36.17		8
2	N. Dak. 1B	Lehigh <sup>e</sup>	L47.81	1.44	25.2	32.32		2
4	Ark. 10	Lester	L47.92	1.68	22.6	32.92	Distilled for oil	4
20	Wyo. 2B	Cambria	48.03	2.99	46.2	36.69	No coking test	20
63	Iowa 3	Altoona	48.77	3.54	62.0	35.68	Makes brittle coke	63
12a	Wyo. 2326	Uinta County	S49.33	2.41	31.5	29.66		12a
9	Wyo. 3	Aladdin	49.59	2.45	38.6	29.78	Burned to ash.	9
51a	Batan	Philippine Is. <sup>d</sup>	S49.71	2.64	28.0	30.95		51a
203	Mo. 4	Barnett	49.76	4.49	94.9	38.32	Cokes fairly well	203
18	Wyo. 2	Cambria	49.86	2.93	40.3	32.36	No test	18
19	Tex. 2	Hoyt	L50.43	2.06	25.1	30.00		19
41	Wyo. 4	Hanna	S50.46	2.52	29.2	32.93		41
57a	Wyo. 3605	Hanna	S50.54	2.71	31.3	33.12		57a
2b	Wyo. 3694	Labarge Range <sup>a</sup>	S50.63	-.37	11.1	17.47		2b
52a	N. Mex. 3952	Near Blackrock	50.69	3.90	56.8	36.10	Makes coke	52a
56	Wyo. 4B	Hanna	S50.82	3.48	37.9	33.29	No test	56
26	Ill. 7A	Collinsville	50.89	2.99	50.0	33.55	Good hard coke on Ill. 7D	26
5	N. Dak. 2B	Williston	L50.93	1.18	26.4	29.67		5
25	Wyo. 1	Monarch	S51.03	2.47	31.1	32.27		25
153	Ind. 10	Rosedale	51.32	4.05	61.6	34.75	No test	153
61	Ill. 1	O'Fallon	51.35	3.35	63.0	33.73	Small pieces of coke in test	61
14	Ill. 2	O'Fallon	51.38	3.05	53.7	32.96	Poor hard and soft coke	14
13	N. Dak. 2	Williston	L51.56	1.74	23.3	28.40		13
51	Ind. 1	Mildred	51.70	3.33	58.1	31.40	Cokes fairly well	51
44a	Wyo. 3693	Labarge Range <sup>b</sup>	S52.06	2.50	29.0	28.85		44a
17	N. Mex. 2	Gallup	S52.07	2.96	43.6	33.29		17
99	Ill. 9B	Staunton	52.29	3.60	53.6	32.62	No test	99
105	Ohio 1	Wellston	52.30	3.60	60.4	32.75	Good heavy coke	105
49	Ill. 7B	Collinsville	52.31	3.30	53.6	32.15	Hard coke on Ill. 7D	49
69	Ill. 30	Shiloh station	52.48	3.40	49.1	31.02	No test	69
55	Ill. 22A	Maryville	52.51	3.12	51.6	31.26	No test	55
52	Iowa 4	Carterville	52.52	3.25	54.9	32.70	Cokes	52
66	Ind. 14	Seelyville	52.70	3.50	56.1	31.28	No test	66
184	Utah 1	Price	52.77	4.02	52.2	34.93	Soft dense coke in test	184
67	Ind. 13	Terre Haute	52.81	3.46	58.3	33.71	No test	67
83	Wyo. 6	Kemmerer	S52.83	3.06	33.9	30.56		83
81	Ill. 9A	Staunton	52.86	3.55	53.7	31.79	No test	81
142	Ind. 7	Littles	52.86	3.91	68.0	33.83	Fair though brittle coke	142
80	Ind. 6	Hymera	52.87	3.71	71.8	33.49	Good light-gray silvery coke	80
48	Iowa 2	Hamilton	53.00	3.45	59.3	30.85	Coked in small pieces	48

DIAGRAM SHOWING HYDROGEN-OXYGEN RATIOS OF COALS.

\* The limits of the diagram include  $\frac{H}{O}$  percentages over 10 and under 290,  $\frac{VC}{C}$  percentages under 57, and available H over 2.7.

No.	Lot.	Locality.	F. C. in pure coal.	* $\frac{H}{O}$ %		VC C %	Remarks.	No
				H- 8	O %			
52b	Wyo. 2325	Almy	53.02	2.28	28.5	30.74		52b
120	Ill. 18	Lasalle	53.13	3.80	56.0	31.80	No test	120
33a	N.Mex. 3811	West of Putnam	53.25	2.93	35.5	28.50		33a
22	Tex. 4	Hoyt	53.27	2.00	25.2	27.29		22
74	Ind. 2	Booneville	53.28	3.54	63.0	32.09	No test	74
87	Ind. 16	Linton	53.41	3.52	57.1	31.75	No test; is coked	87
149	Ind. 7B	Littles	53.50	3.81	60.8	32.48	Cokes well	149
43	Mo. 1	Sprague	53.55	3.58	79.4	32.05	No test	43
32	Colo. 1	Lafayette	53.69	2.63	32.7	29.61		32
72	Ind. T. 4	Lehigh	53.74	3.20	48.8	30.54	No test	72
98	Ind. 5	Hymera	53.75	3.57	60.8	31.77	Makes good coke	98
55a	Wyo. 3698	Labarge Range <sup>b</sup>	53.81	2.46	28.6	27.94		55a
109	Ohio 9B	Clarion	53.83	3.48	54.8	32.18	Good but very brittle coke	109
73c	Wyo. 2283	Mammoth Hill	53.83	2.24	26.5	28.22		73c
38	Ill. 27	Auburn	53.85	3.13	49.5	29.82	Poor soft, dense coke	38
168	Ohio 10	Mineral City	53.91	4.16	57.9	31.89	No test	168
113	Mo. 6	Huntsville	53.95	3.63	67.1	30.85	No test	113
31	Mont. 1	Red Lodge	53.96	2.75	35.6	28.47		31
53	Ill. 25B	Germantown	53.99	3.36	52.4	29.17	No coke on test of Ill. 25A	53
76	Ill. 14	Springfield	54.03	3.60	54.8	30.60	No test	76
107	Ind. 9B	Macksville	54.03	3.73	56.5	31.41	Good heavy coke	107
10	Ind. T. 5	Lehigh	54.07	2.63	48.5	29.28	Small pieces of coke from test	10
94	Ill. 23B	Donkville	54.20	3.54	51.9	29.45	Coked	94
42	Ill. 8		54.20	3.25	54.1	30.22	No test	42
90	Mo. 5	Higbee	54.21	3.60	62.5	30.33	Good coke of good weight	90
15	Mo. 7A	Noringer	54.27	2.87	50.1	29.79	No test	15
130	Ky. 2	Earlington	54.28	3.74	59.7	31.59	Said to coke well	130
66a	Colo. 3498	Meeker	54.45	2.65	31.4	28.41		66a
2a	Mont. 3701	Near Miles <sup>b</sup>	54.46	.99	19.2	30.95		2a
45	Ill. 23A	Donkville	54.48	3.18	50.3	29.18	Coked; light gray	45
172	Ohio 12A	Bellaire	54.55	3.95	67.4	32.20	Good coke	172
81a	Ariz. 411	Near St. Michaels	54.58	3.04	36.1	29.73		81a
28	Mo. 7B	Noringer	54.59	3.11	56.6	29.17	No test	28
24	Tex. 3	Olsen	54.68	2.18	27.1	25.29		24
117	Ind. 8	Terre Haute	54.68	3.77	67.5	31.87	No test	117
62	Ill. 15	Centralia	54.76	3.26	50.9	29.46	No test	62
102	Ind. 9	Macksville	54.76	3.64	59.1	31.21	Fair coke; light-gray silvery	102
138	Kans. 4	Atchison	54.79	4.05	97.9	28.02	Cokes; hard but brittle	138
110a	Wyo. 3891	Mt. McDougal	54.79	2.93	35.0	29.90		110a
154	Ohio 8	Dixie	54.81	3.78	56.0	31.31	Good but brittle coke	154
16	Mo. 3	Mendota	54.93	2.98	52.5	28.61	No tendency to coke on test	16
91	Ind. 12	Hartwell	54.97	3.53	57.0	30.04	Good coke, metallic ring	91
92	Ohio 2	Superior	55.00	3.61	60.5	30.24	Coke soft, poor on test	92
82	Ill. 26	Lincoln	55.14	3.35	53.8	29.34	Poor dull-gray coke	82
40	Ind. 3	Booneville	55.16	3.32	56.4	27.96	No coke from test	40
57	Ill. 29B	Livingston	55.24	3.29	52.2	28.53	No test. Ill. 29 poor coke	57
53a	Wyo. 3917	Fort Steele	55.36	2.02	24.2	23.80		53a
12	Mo. 7C	Noringer	55.43	2.64	44.3	27.58	No test	12

DIAGRAM SHOWING HYDROGEN-OXYGEN RATIOS OF COALS.

\* The limits of the diagram include  $\frac{H}{O}$  percentages over 10 and under 290,  $\frac{VC}{C}$  percentages under 57, and available H over 2.7.

No.	Lot.	Locality.	F. C. in pure coal.	* $\frac{O}{H}$	$\frac{H}{O}$ % *	VC C % *	Remarks,	No.
50	Wash. 1B	Renton	55.56	3.06	37.5	27.89	No test	50
75a	Colo. 3462	Lay <sup>a</sup>	55.65	2.98	35.9	27.62	No coke produced	75a
205	W. Va. 2	Clarksburg	55.71	4.13	77.0	32.16	Good coke, somewhat brittle	205
59	Ill. 29	Livingston	55.82	3.16	47.2	26.80	Poor, dense coke	59
111	Ky. 3	Barnsley	55.99	3.69	61.9	29.64	Fairly good coke	111
137	Ind. T. 3	Edwards	56.08	3.54	60.0	29.86	Unsatisfactory test	137
52c	Colo. 3463	Lay	56.16	2.70	32.1	25.95		52c
73	Ill. 31	Worden	56.33	3.35	51.9	27.62	No test	73
112a	Wyo. 3509	Fort Steele	56.36	3.01	37.3	27.81		12a
175a	Colo. 4225	Near Mancos	56.41	4.17	58.5	30.67	Said to make coke	175a
96	Ill. 24a	New Baden	56.42	3.42	53.6	26.87	No coke from test	96
108	Ky. 4	Wheatcroft	56.46	3.48	68.8	29.63	Good coke, metallic ring	108
73a	Colo. 3490	Book Cliffs field	56.50	3.01	38.8	27.75		73a
39a	Wyo. 3699	Labarge Range <sup>b</sup>	56.51	2.32	27.4	23.37		39a
33	Ill. 29A	Livingston	56.58	3.10	49.0	26.07	Poor, dense coke	33
84a	Colo. 3703	Axial	56.61	2.37	28.4	25.85		84a
46	Wash. 1	Renton	56.66	2.80	36.6	27.37	No test	46
167	Ohio 12B	Bellaire	56.86	3.97	67.3	29.57	Good coke	167
31a	Colo. 3729	Carbonera	56.87	3.30	43.7	27.33	Said to be noncoking	31a
128	Wash. 2	Roslyn	56.88	3.75	54.5	30.64	Very brittle, dense coke	128
146b	Colo. 3586	Book Cliffs field	56.88	3.41	43.4	27.87		146b
131	Ohio 11	Flushing	56.89	3.61	62.7	28.60	Said to coke well	131
75b	Colo. 3704	Axial	57.03	2.50	30.4	25.56		75b
129	Ky. 7	Central City	57.05	3.51	60.4	28.82	Good coke	129
132	Ind. 18A	Winslow	57.12	3.59	68.7	30.11	Once coked commercially	132
77	Ohio 3	Shawnee	57.13	3.29	50.8	28.86	Burned to ashes in test	77
178	Ohio 4	Crow Hollow	57.13	4.04	77.2	30.37	Fine heavy coke	178
64	N. Mex. 1	Gallup	57.16	3.08	39.3	27.10		64
144	Wyo. 5	Rock Springs	57.19	3.08	36.2	26.49	No coke from test	144
171	Ohio 9A	Clarion	57.20	3.40	54.8	29.39	Good but brittle coke	171
160	Ind. T. 2	Hartshorne	57.24	3.88	65.5	31.05	Coked well	160
28a	Colo. 3856	Thompsons	57.27	3.21	46.1	27.73	Noncoking	28a
46a	Colo. 4050	Near Glenwood Springs	57.35	2.58	31.7	24.13		46a
187	Ohio 6	Neffs	57.38	4.19	77.5	30.08	Good coke; metallic ring	187
39b	Wyo. 3780	Northeast of Hanna <sup>a</sup>	57.41	2.79	31.7	20.49		39b
70	Ill. 21	Troy	57.48	3.02	41.9	27.16	No coke from test	70
133	Ky. 9A	McHenry	57.49	3.81	60.0	27.88	Fairly good coking	133
36	Iowa 5	Chariton	57.65	3.78	57.7	25.66	Partially coked in test	36
39	Ill. 4	Troy	57.72	3.01	48.5	28.30	No test	39
75	Ind. 17	Bicknell	57.76	3.17	50.5	26.53	Poor dark-gray coke	75
103	Ind. 18B	Winslow	57.82	3.40	50.8	28.52	No test; said to coke	103
147a	Colo. 3943	Rifle Creek	57.95	3.40	41.1	26.03	Noncoking	147a
173b	Colo. 3939	Newcastle	57.98	3.47	43.9	27.78		173b
101	Ind. 11	Dugger	58.00	3.25	52.1	28.79	Coke; medium cells	101
171a	Colo. 3938	Newcastle	58.08	3.28	40.3	27.03		171a
166a	Colo. 3587	Book Cliffs field	58.14	4.00	55.0	27.96	No test	166a
174a	Colo. 4036	Sunlight	58.19	3.42	39.0	25.82		174a
154a	Wyo. 3480	Fort Steele	58.22	3.46	41.6	25.76		154a

DIAGRAM SHOWING HYDROGEN-OXYGEN RATIOS OF COALS.

\* The limits of the diagram include  $\frac{H}{O}$  percentages over 10 and under 290,  $\frac{VC}{C}$  percentages under 57, and available H over 2.7.

No.	Lot.	Locality.	F. C. in pure coal.	$\frac{H}{O} \%$	$\frac{H}{O} \%$	VC/C*	Remarks.	No.
215	W. Va. 15	Clarksburg	58.28	4.31	101.9	31.26	Very good hard, heavy coke	215
126	N. Mex. 4A	Brilliant	58.32	3.88	63.1	29.44	Coked well	126
134a	Colo. 3541	Book Cliffs field	58.34	3.08	39.3	26.26		134a
146	Ind. T. 1	Henryetta	58.35	3.72	59.3	28.34	No coke from test	146
118	N. Mex. 4B	Brilliant	58.48	3.89	65.2	29.45	Good heavy coke	118
29	Mont. 2	Fromberg	58.49	2.68	35.2	24.50	No test	29
158	Tenn. 7A	Wilder	58.50	4.05	83.2	28.95	Coked	158
37	Mont. 3	Bridger	58.53	2.70	34.4	24.34		37
211a	Colo. 3552	Near Durango	58.54	4.05	62.9	29.24	Cokes	211a
171b	Colo. 3585	Book Cliffs field	58.62	3.83	53.8	27.45	No test	171b
146a	Colo. 3946	Rifle Creek	58.75	3.26	38.2	24.65		146a
101a	Colo. 3550	Book Cliffs field	58.79	3.53	49.9	30.57	Noncoking	101a
54	Ill. 9C	Staunton	58.83	3.01	48.3	24.33	No test	54
179a	Colo. 4048	Sunlight	58.91	3.53	42.0	25.34		179a
68	Ind. 4	Star City	58.99	3.24	52.0	26.04	Coke with poor structure	68
148	Ohio 7	Danford	59.00	3.84	69.8	27.49	Good coke	148
160a	Colo. 3936	Newcastle	59.01	3.39	43.3	26.70		160a
136	Ind. 15	Linton	59.03	3.55	56.4	27.29	No test	136
23	Mo. 10	Bevier	59.04	2.84	47.6	23.19	No test	23
78	Ill. 12	Bush	59.10	3.35	55.0	25.46	No test	78
34	Ind. 20	Brazil	59.14	3.20	57.6	26.62	No test	34
188	Ind. T. 2C	Hartshorne	59.18	4.04	73.8	28.75	Commercial coke	188
176a	Colo. 7573	Hesperus	59.19	3.77	52.5	27.74	Said to coke poorly	176a
44	Ill. 6	Coffeen	59.22	3.11	44.7	21.50	No test	44
125	Ind. T. 2B	Hartshorne	59.25	3.55	67.6	28.43	Said to coke well	125
47	Ill. 21B	Troy	59.33	2.98	43.2	25.29	No coke from test	47
207	Tenn. 2	Gatliff	59.38	4.07	68.7	29.53	Good coke	207
100	N. Mex. 3C	Van Houten	59.39	3.63	59.1	28.30	No test; cokes well.	100
60	Iowa 1	Laddesdale	59.42	3.25	64.3	24.74	Makes brittle coke	60
58	Ill. 6B	Coffeen	59.42	3.18	50.1	22.90	No test	58
71	Ill. 22B	Maryville	59.43	3.24	51.1	28.86	Poor dull-gray coke	71
110	Ill. 10	West of Frankfort	59.55	3.47	52.1	26.25	No test	110
93	N. Mex. 3B	Van Houten	59.59	3.48	57.8	27.97	Good heavy coke	93
217	Va. 4	Darby	59.60	3.91	63.9	29.30	Good coke	217
183	Ohio 5	Rush Run	59.79	3.84	60.2	27.27	Good but brittle coke from test	183
86	N. Mex. 3A	Van Houten	59.87	3.76	63.9	27.75	Commercial coke	86
79	Kans. 2	Yale	59.91	3.72	91.5	24.56	Imperfect test	79
165	Ill. 34A	Harrisburg	59.97	3.64	54.5	25.42	No test	165
161a	Wyo. 4323	Greys	59.98	2.84	32.0	22.76		161a
219	W. Va. 1	Kingmont	60.00	4.31	79.7	29.31	Good coke	219
177	W. Va. 25	Charleston	60.03	3.65	52.4	27.06	Fair brittle coke	177
164	Tenn. 8A	Clifty	60.08	4.28	106.1	27.24	Cokes well	164
135	Ky. 9B	McHenry	60.15	3.63	57.2	24.67	No test; said to coke well	135
115	Ind. T. 8	Railroad car	60.16	3.57	64.8	26.86	No test	115
143	Kans. 1	Fleming	60.17	3.87	90.2	26.69	Imperfect test	143
157	Tenn. 8B	Clifty	60.23	3.88	101.6	26.90	Makes good coke	157
185	Tenn. 5	Petros	60.28	4.16	90.4	27.19	Good heavy coke	185
234	W. Va. 21	Winifrede	60.28	4.23	77.5	28.75	Good hard, heavy coke	234

DIAGRAM SHOWING HYDROGEN-OXYGEN RATIOS OF COALS.

\* The limits of the diagram include  $\frac{H}{O}$  percentages over 10 and under 290,  $\frac{VC}{C}$  percentages under 57, and available over 2.7.

No.	Lot.	Locality.	F. C. in pure coal.	* $\frac{H}{O}$ %	* $\frac{H}{O}$ %	VC %	Remarks.	No.
224	Ky. 6	Miller Creek	60.39	4.00	61.4	27.95	Good but brittle coke	224
88	Kans. 6	Jewett	60.54	3.57	73.2	25.32	Cokes well	88
186	Tenn. 3	Gatliff	60.56	4.08	64.1	26.75	Good but brittle coke	186
173a	Wyo. 3570	Oyster Ridge	60.61	3.31	43.2	25.45		173a
119	Ill. 11B	Carterville	60.68	3.57	59.4	25.00	No test	119
171c	Colo. 3932	Newcastle	60.71	3.52	45.5	24.99		171a
208a	Wyo. 4303	Willow Creek	60.74	3.46	44.5	25.13		208a
104	Ill. 34 B	Harrisburg	60.76	3.33	52.3	23.84	Coked well	104
155	Pa. 13	Creighton	60.77	4.15	83.7	27.17	No test; said to coke well	155
156	Tenn. 1	Fork Ridge	60.84	3.80	65.3	26.14	Good strong, hard, heavy coke	156
112	Ill. 12B	Bush	60.87	3.33	53.1	24.70	No test	112
72a	Colo. 3545	Book Cliffs field <sup>a</sup>	60.89	2.96	37.0	21.63		72a
215a	Wyo. 4299	Willow Creek	60.91	4.20	58.8	26.68	No test	215a
114	Ala. 2	Carbon Hill	60.95	3.43	52.5	25.27	Coked imperfectly	114
229	Ky. 1	Straight Creek	60.96	4.26	72.6	27.11	Coked commercially	229
122	Ill. 13	Benton	61.02	3.41	52.7	24.73	Dull-gray coke	122
116	Ill. 12 C	Bush	61.02	3.45	55.2	24.35	No test	116
175	W. Va. 22 B	Hernshaw	61.02	4.01	70.4	27.45	Good coking coal	175
209	W. Va. 23A	Monarch	61.18	4.14	76.2	27.51	Good coking coal	209
149a	Colo. 3546	Book Cliffs field	61.19	3.48	46.4	23.86		149a
199	W. Va. 23 B	Monarch	61.23	4.01	70.3	27.03	Cokes well	199
170	Ill. 11C	Carterville	61.30	3.64	54.1	24.67	No test; strong coke on Ill. 11D	170
218	Va. 2 B	Crab Orchard	61.42	4.04	70.2	27.37	Very good coke	218
204	Ky. 1B	Straight Creek	61.43	4.11	78.6	27.34	Coked commercially	204
145	Ill. 11	Carterville	61.48	3.50	57.0	24.60	No test	145
141	N. Mex. 5	Blossburg	61.49	3.84	72.5	27.30	Good heavy coke	141
146c	Wyo. 4302	Willow Creek <sup>b</sup>	61.60	2.69	35.6	22.84		146c
62a	Utah 4013	South of Sunnyside <sup>a</sup>	61.62	2.20	26.6	17.99		62a
221	Va. 1	Crab Orchard	61.70	4.04	66.4	26.52	Good hard coke	221
220	Pa. 10	Bruce	61.71	4.19	78.0	27.02	Makes good coke	220
233	Ky. 5	Big Black Mountain	61.91	3.83	61.5	26.49	Good but very brittle coke	233
208b	Colo. 4010	Gulch	61.97	3.98	60.0	25.63	No test; said to coke	208b
127	Ill. 12 D	Bush	62.22	3.31	49.6	22.19	No test	127
169	Pa. 6	East of Millsboro	62.26	3.87	85.4	26.55	Makes fine coke	169
192	W. Va. 22A	Hernshaw	62.27	3.94	64.3	25.80	Good coking coal	192
226	Pa. 5	Ellsworth	62.31	4.27	81.8	26.90	Fine coking coal	226
85	Ala. 2B	Carbon Hill	62.31	3.13	48.6	23.33	Soft, dense, dull coke	85
214	Pa. 11	Charleroi	62.46	4.14	77.1	26.24	Cokes well	214
136a	Colo. 3640	Book Cliffs field	62.54	3.27	39.2	20.80		136a
159	Ala. 1	Horse Creek	62.59	3.98	74.1	25.56	Cokes well	159
147	Ill. 19B	Ziegler	62.64	3.47	60.9	24.99	No coke from test	147
174	Tenn. 4	Oliver Springs	62.69	4.05	70.3	26.09	Is coked	174
84	Ill. 19E	Ziegler	62.74	2.66	38.3	22.08	No coke from test	84
173	Kans. 5	West of Mineral	62.92	4.04	82.6	23.54	Said to coke	173
65	Kans. 2 B	Yale	63.15	3.62	107.9	22.71	No test	65
95	Ill. 19 C	Ziegler	63.26	3.41	54.1	23.09	No coke from test	95
97	Ill. 3	Marion	63.26	3.30	55.4	22.50	Poor brittle coke	97
201	W. Va. 16.	Monongah	63.27	3.85	71.9	25.14	Good hard, heavy coke	201

DIAGRAM SHOWING HYDROGEN-OXYGEN RATIOS OF COALS.

\* The limits of the diagram include  $\frac{H}{O}$  percentages over 10 and under 290,  $\frac{VC}{C}$  percentages under 57, and available H over 2.7.

No.	Lot.	Locality.	F. C. in pure coal.	* $\frac{H}{O}$	$\frac{H}{O}$ %*	VC %	Remarks.	No.
139	Ill. 16	Herrin	63.29	3.42	54.9	22.94	No test	139
242a	Ala. 3770	Sydenon	63.58	4.51	93.7	26.52	Cokes well	242a
216a	Ala. 3771	Acton Basin	63.59	4.09	72.5	25.32	Cokes well	216a
231	W. Va. 18	Glen Alum	63.61	3.99	76.3	25.88	Good hard, heavy coke	231
231a	Ala. 3744	Fallston	63.69	4.00	58.6	23.67	Coking coal	231a
124	Ill. 28 C	Herrin	63.76	3.29	52.2	22.19	Dark-gray coke; small cell structure	124
135a	Ill. 19 D	Ziegler	63.80	2.87	42.2	21.77		135a
227a	Ala. 3769	Acton Basin	63.87	3.91	65.4	24.37	Good coking coal	227a
222	W. Va. 20	Acme	63.88	4.34	100.6	25.79	Good hard, heavy coke	222
202	Pa. 19	Hermine	63.98	3.95	70.1	24.13	Good heavy coke	202
180	Ky. 8	Sturgis	64.23	3.68	61.9	23.35	Fairly good coke; large cells	180
210a	Ala. 3745	Coalmont	64.23	3.84	61.8	23.63	Said to coke well	210a
73b	Mont. 4115	Stocket district	64.39	2.75	41.8	19.16		73b
134	Ala. 3	Garnsey	64.41	3.42	60.7	23.62	Strong, hard, heavy coke	134
166	Ala. 4	Belle Ellen	64.59	4.14	93.9	24.56	Fine strong coke	166
223	W. Va. 8	Ansted	64.72	4.35	99.4	25.18	Fine coking coal	223
197	Pa. 4	Greensburg	64.98	4.11	95.7	24.42	Makes excellent coke	197
106	Ill. 12	Ziegler	65.00	3.07	48.4	21.13	No coke from test	106
191	Pa. 12	Atcheson	65.58	3.84	74.2	21.69	Very good coke	191
44b	Mont. 3515	Belt district	65.74	2.88	51.1	17.71		44b
243	Va. 3	Coeburn	65.77	4.30	96.1	24.31	Good heavy commercial coke	243
208c	Ala. 3499	Lovick	65.79	3.99	77.5	22.46	Said to make good coke	208c
198	W. Va. 3	Richard	65.87	4.15	92.3	23.31	Said to coke well	198
25a	Mont. 3512	Belt distric	65.91	2.27	32.9	15.09		25a
150	Tenn. 6	Waldencia	66.20	3.85	81.0	22.80	Good strong, heavy coke	150
245	W. Va. 13	Loup Creek	66.39	4.41	103.1	23.83	Very good coke; commercial	245
89	Tenn. 9 B	Coalmont	66.53	3.92	89.6	21.95	Commercially coked	89
194	Tenn. 9 C	Coalmont	66.59	3.92	77.8	22.40	Makes a good coke	194
151	Tenn. 9 A	Coalmont	66.78	3.80	80.6	21.74	Good coke	151
176	Pa. 17	White	66.84	4.11	97.5	21.83	Good heavy coke	176
189	Pa. 22	Huff	67.23	3.97	82.9	21.30	Good coking coal	189
200	W. Va. 5	Coalton	67.25	4.01	83.6	21.46	Makes good coke; high ash	200
196	Pa. 21	Connellsville	67.66	3.69	68.4	20.30	Excellent standard coke	196
232	W. Va. 9	Powellton	68.00	4.24	89.6	21.02	Coked commercially	232
121	Ala. 5	Lehigh	68.02	3.60	81.1	19.96	Good, heavy, silvery coke; metallic	121
239	W. Va. 14	Loup Creek	68.28	4.13	78.1	20.02	Good, hard, commercial coke	239
216	W. Va. 4	Bretz	68.29	4.09	90.5	20.89	Good coke with cross fracture	216
21	Mexico 1		68.36	3.18	69.7	19.12	No test	21
208	W. Va. 4 B	Bretz	68.93	3.81	97.5	20.65	Very good coke	208
225	W. Va. 17	Near Bretz	69.13	3.85	99.6	20.61	Very good coke	225
27	Tenn. 11	Ozone	69.74	3.35	101.1	18.97	Poor coke from test	27
235	Ala. 6	Dolomite	70.95	4.10	91.6	18.41	Heavy, light-gray silvery coke	235
210	Va. 6	Richlands	72.39	3.76	89.7	16.11	Dense coke from test	210
227	Pa. 16	Hastings	75.21	3.79	87.5	12.94	No test. Said to coke	227
249	W. Va. 19	Mc Donald	75.28	4.14	129.7	15.14	Good coking coal	249
193	Pa. 7	Ligonier	75.30	4.05	152.0	13.69	Good heavy coke	193
231b	Colo. 4047	Coal Basin	76.24	4.08	116.9	13.41	Makes good coke	231b
248	W. Va. 6	Rush Run	76.94	4.17	126.5	13.26	Tough, dense coke; commercial	248

DIAGRAM SHOWING HYDROGEN-OXYGEN RATIOS OF COALS.

\* The limits of the diagram include  $\frac{H}{O}$  percentages over 10 and under 290,  $\frac{VC}{C}$  percentages under 57, and available H over 2.7.

No.	Lot.	Locality.	F. C. in pure coal.	H-O 8	H% O*	VC% C*	Remarks.	No.
195	Ark. 3	Jenny Lind	77.40	3.46	94.8	11.41	No test	195
240	W. Va. 7	Sun	78.18	3.65	82.8	10.63	Good quality coke	240
35	Ark. 9	Bonanza	78.97	2.88	73.7	7.71	No coke from test	35
230	Pa. 15 B	Wehrum	79.23	4.02	215.2	9.07	Cokes in by-product ovens	230
182	Ark. 1	Huntington	79.25	3.41	105.8	10.00	Soft, dense coke; poor cells	182
123	Ark. 1 B	Huntington	79.66	3.36	115.3	9.40	Burned in test.	123
237	Pa. 15	Wehrum	79.77	4.20	288.8	9.11	Soft dense coke in test; coked in by-product ovens	237
212	Pa. 9	Kimmelton	79.91	3.55	125.5	9.42	Pieces of coke in charge on test	212
250	W. Va. 10	Mora	80.15	4.18	169.6	11.63	Good hard, heavy coke	250
206	Ark. 7A	Midland	80.36	3.50	101.0	7.64	No test. Test of Ark. 7 B. produced no coke	206
181	Ark. 12		80.45	3.26	118.5	9.15	No test	181
247	W. Va. 12	Big Sandy	80.47	4.64	295.7	10.58	Good large coke	247
246	W. Va. 12A	Big Sandy	80.47	3.98	173.0	11.06	Good coke	246
161	Ga. 1	Menlo	80.57	3.39	79.9	6.73	Poor dense coke from test	161
213	W. Va. 11	Zenith	80.73	3.56	128.4	10.55	No coke from test; said to make good coke	213
190	Md. 1	Georges Creek	80.94	3.42	132.6	9.02	Poor soft coke	190
244	Pa. 8	Ehrenfield	81.28	3.94	149.8	9.49	Soft dense coke from test	244
241	Md. 2	Frostburg	81.36	4.11	161.1	10.39	No test. Poor coke once shipped	241
228	Pa. 20	Seward	81.41	4.28	250.0	7.74	Soft dense coke from test	228
236	Ark. 2	Bonanza	81.92	3.73	159.5	7.96	No tendency to coke on test; burned to ashes	236
238	Pa. 18	Lloydell	82.27	4.16	167.5	7.49	No test	238
30	W. Va. 24	Gary	82.87	2.83	93.2	6.02	No test; said to be coked	30
239a	Ark. 3174	Paris	83.34	3.61	250.0	6.65	No test	239a
239b	Pa. L	Johnstown	83.89	3.67	164.0	5.82		239b
242	Ind. T. 9	Panama district	84.29	4.07	253.2	6.58	No test	242
211	Ark. 5	Coal Hill	85.18	3.35	162.1	4.65	No test	211
162	Va. 5B	Blacksburg	86.50	3.49	151.4	4.48	No test	162
140	Va. 5A	Blacksburg	86.89	3.10	104.4	3.20	No test	140
179	Ark. 8	Spadra	87.01	3.01	122.7	2.93	No test	179
163	Pa. 3	Scranton	91.09	2.30	115.7	1.18	No test	163
152	R. I. 1	Providence	93.73	.31	244.3	1.98	Not a fuel	152

DIAGRAM SHOWING HYDROGEN-OXYGEN RATIOS OF COALS.

\* The limits of the diagram include  $\frac{H}{O}$  percentages over 10 and under 290,  $\frac{VC}{C}$  percentages under 57, and available H over 2.7.

## APPLICATION TO ALGAL HYPOTHESIS.

Applying these observations to our tentative hypothesis to account coincidentally for both bituminization and fusibility, the conclusion that gelosic (or sapropelic) elements have entered into the composition of certain of the coals in the list seems justified. So far as the coals low in fixed carbon are concerned, I am disposed to regard it as essentially confirmed.

The Barnett, Mo., coal (No. 203) with a fixed carbon (pure coal) percentage of 49.76 and a H:O ratio of 94.9 I regard as most probably gelosic (sapropelic). So also with the coal from Sprague, Mo. (No. 43), with 53.55 fixed carbon and 79.4 H:O ratio, and Atchison, Kans. (No. 138), with 54.79 fixed carbon and 97.9 H:O ratio. I have not personally examined specimens from any of the above-mentioned coals. Provisionally, I am inclined to believe that small portions of gelosic matter probably entered into others of the coals whose ratio percentage is conspicuously above that of the associated bituminous coals having nearly the same percentage of fixed carbon, though lower than those mentioned. Among the most prominent of these mention may be made of Stone Canyon, Cal. (No. 147b), with 46.22 fixed carbon; Altoona, Iowa (No. 63), with 48.77; Hymera, Ind. (No. 80), with 52.87; Clarksburg, W. Va. (Nos. 205 and 215), with 55.71 and 58.28, respectively; Wilder, Tenn. (No. 158), with 58.50; Yale, Kans. (No. 79), with 59.91, and Clifty, Tenn. (No. 164), with 60.08. If an unknown, probably very small, amount of gelatinous algal matter entered into the composition of these coals, it probably has been optically obliterated, if not quite macerated. In passing it may be remarked that the provisional hypothesis appears to harmonize in all respects with the tendency of the coking coals to cohere when reduced to a fine powder under the pestle, discovered by Max Pishel<sup>a</sup> since the preparation of these tables.

## COKING OF HIGH FIXED CARBON COALS.

## VOLATILE-CARBON RATIOS.

The reader will have noted in passing down the H:O ratio columns in Plate III that after reaching a fixed carbon in pure coal of 66 or 67 per cent, H:O ratios of 60 per cent or over characterize all the coals. Accordingly it should follow that all these coals possess the fusing quality and are susceptible of coking. This is practically true, for it appears that nearly all the coals in this portion of the list will coke up to a fixed carbon of about 79 per cent, beyond which, as may be noted in the "remarks," some of the coals do not coke well by the ordinary

<sup>a</sup> Econ. Geology, vol. 3, No. 4, 1908, p. 265.

process, while others apparently refuse to coke. A typical example of the latter kind is No. 35 from Bonanza, Ark., with 78.97 fixed carbon and a ratio of 73.7. Inspection of the columns of VC:C ratios shows that the high fixed carbon coals which apparently are noncoking are relatively low in volatile carbon, while certain other coals with a fixed carbon as high as 80 are said to coke well, although sometimes with considerable waste of uncemented carbon. The volatile of these high fixed carbon coking coals, it will be observed, seems to be characterized by a relatively high proportion of carbon. According to the tests, and so far as the present series of analyses illustrates, it would seem that coals of over 79 per cent of fixed carbon in pure coal can not be depended upon for coking by the ordinary process if the volatile carbon to carbon ratio (VC:C) is less than 10 per cent. Several of these highest-grade semibituminous coals, which are approaching the semianthracite group and whose volatile carbon ratio is less than 10, are said to give good results in by-product ovens. An example is No. 237 from Wehrum, Pa., in which the fixed carbon is 79.77 per cent and the VC:C ratio 9.11 per cent.

#### CONSULTATION OF EFFICIENCY ERRORS.

Another method of distinguishing the coking from the noncoking coals in this group with over 78 or 79 per cent of fixed carbon, more practical and perhaps more reliable than observation of the volatile carbon ratios, is consultation of the efficiency errors, for the examples before us seem to indicate that the highly developed coals which do not possess the coking quality show very marked deficiency errors. This is well illustrated by the analyses of the higher semibituminous and the semianthracite fuels from Arkansas.

#### HYDROGEN AND OXYGEN LOSSES IN THE PROGRESSIVE DEVELOPMENT OF COAL.

An explanation of the general upward progress of the hydrogen-oxygen ratios in coals of over 66 per cent fixed carbon (all such in the tables being high) may be found in the more unequal rate of loss in the hydrogen and the oxygen during the more advanced stages of the progressive devolatilization of the coals. Observation of the relative loss of hydrogen and oxygen in the different groups of coals (dry-coal basis) shows that the curve of the hydrogen, though inclined steeply at first in passing from cellulose and lignose through the peats into the lignites, grades very gently through the great body of subbituminous, bituminous, and lower semibituminous coals, but pitches more rapidly near the semianthracite rank. The oxygen curve, on the contrary, exhibits a much steeper gradient, dropping

through a much wider range, while passing through the subbituminous and bituminous coals; but before reaching the semibituminous coals it begins to decline more rapidly than the hydrogen curve, and this acceleration continues, so that in many coals the oxygen percentage, as will have been noted, becomes considerably less than the hydrogen. Examples are Nos. 179, 190, 193, 211, 212, 213, 228, 230, 231b, 236, 237, 239a, and 239b. This relatively accelerated loss of oxygen as compared with that of hydrogen is expressed in the increase of the ratios.

#### AVAILABLE HYDROGEN AS INDEX OF COKING COALS.

I have been very greatly interested since the completion of the first draft of this table in December to learn from my chemical colleagues of the well-known hypothesis of the dependence of the coking principle upon the relative amount of available hydrogen. This method of determining from the ultimate analyses whether coals will coke, which has been discussed by Percy, is said to apply successfully in certain areas and groups of coals, though in other groups and regions it is regarded as a failure.<sup>a</sup> On account of the unusually wide range in age, kinds, and characters of the coals represented in the accompanying tables, it has been very interesting to compare the available hydrogen with the observations as to the coking quality. In the column to the right in Table 2 will be found the available hydrogen of all the coals. The same data are transferred, with their corresponding numbers, to Plate III, in which they are platted as light broken lines. Examination of the hydrogen percentages in this table shows that while they tend to parallel the H:O ratios there are many variances, because in general high total hydrogen means high available hydrogen, but not necessarily a high ratio with oxygen.

The diagram shows that while practically all the coals with an available hydrogen of 3.80 or more will coke well unless they are too high in fixed carbon, some good cokes result from fuels with less than 3.50. Several of the tests show cokes from coals with as low as 3.20 available hydrogen. Note the following examples:

#### *Coking coals with low available hydrogen.*

No.	Fixed carbon.	Available hydrogen.	No.	Fixed carbon.	Available hydrogen.
10	54.07	2.63	85	62.31	3.13
14	51.38	3.05	124	63.76	3.29
26	50.89	2.99			

<sup>a</sup> For discussion of the relation of the available hydrogen to the coking quality, see Fulton, John, *Coke: a treatise on the manufacture of coke and other prepared fuels, and the saving of by-products*; Scranton, 1905, pp. 31-38.

Other coals with much higher available hydrogen fail in the tests, as shown in the following examples:

*Noncoking coals with high available hydrogen.*

No.	Fixed carbon.	Available hydrogen.	No.	Fixed carbon.	Available hydrogen.
31a	56.87	3.30	147a	57.95	3.40
40	55.16	3.32	236	81.92	3.73
96	56.42	3.42			

This method also breaks down in the highest semibituminous coals. The loss in volatile in most of the coals of that category leads to a falling off in the available hydrogen. However, on account of the relatively more rapid oxygen loss in the higher coals the available hydrogen percentages sometimes persist after the coal refuses to coke, as in the Bonanza, Ark., coal (No. 236).

It may have been its failure as a coking index for the coals which are approaching semianthracitization at the Allegheny Front, in Cambria County, Pa., that led Fulton<sup>a</sup> to regard this method as of doubtful reliability.

#### HYDROGEN-OXYGEN RATIO THE BEST INDEX.

On the whole it is fairly evident that in coals of less than 79 per cent fixed carbon (in pure coal) the H:O ratios, dry-coal basis, offer surprisingly reliable, narrowly defined, and logical criteria for determining the presence of the coking quality from the ultimate analysis. It has also been noted that in the succeeding and higher coals coking is generally possible if the amount of carbon in the volatile is relatively large; also that most of the coals whose H:O ratio is high but which refuse to coke are clearly distinguished by their marked calorific deficiency with reference to the C:(O+ash) ratio and efficiency curve.

#### STATUS OF ALGAL HYPOTHESIS.

Since practically all coals in the table having fixed carbon contents of 66 per cent or over are found to show high H:O ratios, and possess the coking capacity thereby indicated, the provisional alga-element hypothesis can not be regarded as demonstrated by the ultimate chemical analysis; that is, it does not seem tenable to conclude that all of these coals fuse by reason of the presence of an alga-element. Yet the tentative hypothesis appears to have such strong support in coals of higher volatile that it commands respect-

<sup>a</sup> Fulton, John, Coke and coke making. Ed. 1905, p. 31.

ful consideration. It appears that in the course of the concentrations incident to progressive devolatilization, more rapid loss of oxygen brings about in the higher coals the same approach to bituminization (high H:O ratios) that in the lower coals resulted from the nature of the ingredient matter. That sapropelic influences, even in the higher coals, bear directly on the best coking results is not precluded from possibility. The conspicuous tendency of the recognized alga coals to preserve not only a high hydrogen but also a very high percentage of volatile carbon, may perhaps account for the persistence of relatively high carbon in the volatile, and for the apparently concomitant tendency to fuse, in some of the semi-bituminous coals which have fixed-carbon contents of 80 per cent or more. Examples of such high-volatile carbon coals are the following:

*Coals high in fixed carbon, showing also high volatile carbon ratios.*

No.	Location.	Fixed carbon.	VC:C ratio.	No.	Location.	Fixed carbon.	VC:C ratio.
241	Frostburg, Md. ....	81.36	10.39	246	Big Sandy, W. Va. ....	80.46	11.06
213	Zenith, W. Va. ....	80.73	10.55	250	Mora, W. Va. ....	80.15	11.63

#### MIXTURE OF COALS FOR COKING.

The data given in Plate III are rich in suggestions as to blending of coals in order to obtain either the best coking results,<sup>a</sup> or successful treatment of coals that refuse to coke well by the ordinary process. These suggestions relate not only to the mixing, according to the practicabilities of the regional trade conditions, of coals with relatively high H:O ratios and moderate fixed carbon, like that at Blossburg, N. Mex.,<sup>b</sup> with others whose ratios are hardly up to the standard for good fusion; but also to the mingling of certain coals high in fixed carbon with others rich in volatile matter—that is, high in hydrogen and carbon. For example, the high H:O ratios of the rich-volatile coals listed below promise mutually beneficial economies if finely ground and mixed with such coals high in fixed carbon as those in the second part of the table, more especially since in some of the latter there appears to be waste of fixed carbon when coked by the ordinary process.

<sup>a</sup> The sulphur and ash which so thoroughly control the market value of the coke are not considered in this discussion. For percentages of these, see Tables 1 and 2.

<sup>b</sup> See No. 141 (F. C. 61.49, H:O ratio 72.5); also Brilliant and Van Houten: No. 126 (F. C. 58.32); No. 118 (F. C. 58.48); No. 100 (F. C. 59.39), and No. 86 (F. C. 59.87). It would be interesting to note trials of coals such as No. 138, from Atchison, Kans. (F. C. 54.79), or Sprague, Mo., No. 43 (F. C. 53.55), or Hartshorne, Ind. Ter., No. 125 (F. C. 59.25) when comminuted and mixed for the ovens with some coals with lower ratios from the Rocky Mountain coal fields; though the sulphur and ash of Nos. 138 and 43 are too high for tolerance in commercial coke.

*Comparison of two classes of coals suggested for mixing.*

## COALS RICH IN VOLATILE MATTER, WITH HIGH H:O RATIOS.

No.	Locality.	Fixed carbon.	H:O ratio.	No.	Locality.	Fixed carbon.	H:O ratio.
		<i>Per cent.</i>	<i>Per cent.</i>			<i>Per cent.</i>	<i>Per cent.</i>
155	Creighton, W. Va.....	60.77	83.7	193	Ligonier, Pa.....	75.30	152.0
164	Clifty, Tenn.....	60.08	106.1	205	Clarksburg, W. Va.....	55.71	77.0
167	Bellaire, Ohio.....	56.86	67.3	215	do.....	58.28	101.9
169	East Millsboro, Pa.....	62.26	85.4	222	Acme, W. Va.....	63.88	100.6
172	Bellaire, Ohio.....	54.55	67.4				

## COALS HIGH IN FIXED CARBON.

30	Gary, W. Va.....	82.87	93.0	228	Seward, Pa.....	81.41	250.0
161	Menlo, Ga.....	80.57	79.9	230	Wehrum, Pa.....	79.23	215.2
212	Kimmelton, Pa.....	79.91	125.5	244	Ehrenfeld, Pa.....	81.28	149.8
213	Zenith, W. Va.....	80.73	128.4				

It is possible that some of the coals last mentioned or some of those farther north in Pennsylvania might mix to advantage with some of the high-volatile and high-ratio coals of Michigan, the Lower Verne coal for instance.

**GENERAL OBSERVATIONS ON THE TABULATED COALS.**

## RANGE OF THE SAMPLES.

A general view of Plate III shows the wide range of the coals which have been investigated by the United States Geological Survey. The ultimate analyses, standardized under the direction of N. W. Lord, include most of the commercial coals and extensive coal areas of the country.

## RANK OF PEATS AND LIGNITES.

It is interesting to note that although the peats (Nos. 1 and 6, marked P), not having been subjected to the action of dynamochemical agencies, naturally gravitate to the foot of the scale of fixed carbon percentages, they are preceded in the scale by the Fort Union (Eocene) brown lignite from Glendive, which consists largely of a compressed accumulation of logs and sticks. The low fixed carbon of this coal is probably due to the lack of maceration or putrefaction previous to the development of antiseptic conditions. With the development of asepticity in a coal-forming mass, no further obliteration of the vegetal structures occurs except such as result from infiltration and compression (deformation). In the normal course of events the dynamochemical influences follow.

Following the peats are mingled brown coals (denoted by L) and subbituminous coals (S) more familiarly known as "black lignites." Interspersed among both of these types occur some of the lower grade

bituminous coals as recently classified by M. R. Campbell by their color and characteristics of weathering. Among the latter are several which, as we have already noted, appear to be somewhat gelosic (sapropelic), a relatively low fixed carbon being characteristic of that type of coal.

#### EXPLANATION OF HIGH OXYGEN.

Remembering that the hydrogen-oxygen ratios are based on moisture-free coal, the persistence of a relatively high oxygen content and consequently low ratio, even in certain of the coals of moderate fixed carbon, is striking. Excluding the coals that have taken up oxygen as a result of exposure or weathering,<sup>a</sup> the high oxygen of the low-ratio coals remaining in any group characterized by a definite fixed carbon may be explained either by (1) abundant natural charcoal, which has given the sample an abnormally high fixed carbon, or (2) differences in the original ingredients and conditions of deposition which have given the coal a chemical aspect approaching that of humic or ulmic acid, in contrast to the coals whose high H:O ratios give them a bituminous aspect.

#### QUANTITATIVE RELATION OF VOLATILE CARBON AND HYDROGEN.

One of the most significant features indicated graphically in Plate III is the relations suggested by the two sorts of volatile ratios. The rapid increase in fixed carbon in the peats and lignites at the beginning of the column is of course accompanied by a decrease in the volatile carbon, as expressed by the VC:C ratios. This decrease is nearly parallel to the decrease in volatile combustible matter which is the difference between the fixed carbon and "pure coal." But even before the lignites are passed over it is evident that to a certain extent a coordinate relation exists between the volatile carbon and the hydrogen. The coals whose hydrogen is relatively high as compared to the oxygen are seen almost invariably to have a high volatile carbon; so that the lines representing the two ratios tend conspicuously to approach or withdraw from each other throughout the greater part of the diagram. The Barnett (Mo.) coal (F. C. 49.76) shows this especially well, and evidently has a very large proportion of both hydrogen and carbon in the volatile. Presumably these two elements are largely in chemical union at the moment of escape. On the other hand the distant retreat of the ratios in the weathered coal from the Labarge Range (F. C. 50.63) shows most convincingly a great amount of highly anticalorific oxygen, evidently the overwhelming component in the volatile combustible matter.

<sup>a</sup> Coals with *a*, *b*, and *d* affixed to their locality, in Pl. III, are examples more or less affected by exposure.

## LOSS OF VOLATILE MATTER.

Some points relating to the devolatilization of the coals deserve special notice. The relative decrease of the volatile-carbon ratios as compared to the increase in the fixed carbon column seems to be rapid in passing from 40 to 50 per cent fixed carbon. Above this the relative loss of volatile carbon is slight up to near 63, but still higher the loss appears slightly to accelerate; and in the coals having 70 per cent or more of fixed carbon the ratios seem to fall off a little more rapidly. The unusually low volatile-carbon ratios of the noncoking high semi-bituminous coals is well seen in the retreat of the VC:C lines for these coals in Plate III.

The falling off of carbon in the volatile of the higher coals is accompanied by a general decrease in the oxygen as compared to the hydrogen. The higher H:O ratios show that the volatiles are becoming richer in hydrogen and lower in oxygen in passing to the semianthracite group. At the same time, however, the amounts of available hydrogen fluctuate in marked reactions, though tending to hold their own fairly well from 65 to 75 per cent fixed carbon. Above this they react wildly, and on approaching the anthracites they decline rapidly, regardless of the H:O ratios. Yet, as I remarked in the discussion of the curve variance, the loss in calorific efficiency in the latter coals seems to me disproportionately large as compared to the loss of available hydrogen.

**RELATION OF STAGE OF COAL FORMATION TO CLASSIFICATION.**

## LIKE ANALYSES FOR COALS OF DIFFERENT ORIGIN.

In passing down the columns of Plate III the reader will doubtless have noted that the middle-grade bituminous coals of the Cretaceous and Tertiary mingle with the lower-grade coals from the Eastern Interior basin, and are like them as to fixed carbon contents, H:O ratios, and relative volatile carbon. So it is also in the higher bituminous coals. There are in general no appreciable differences to be noted in the ultimate chemical analyses. In illustration of this fact, attention may be called to the agreement in fixed carbon, hydrogen-oxygen ratios, and volatile-carbon ratios, as well as in the actual percentages of composition, between such coals as those from the Raton-Trinidad district<sup>a</sup> of upper Cretaceous age, and the high-grade eastern, Paleozoic coals with which they are associated in the table; or, to cite a specific illustration, between Van Houten, N. Mex. (No. 86, F. C. 59.87) and Rush Run, Ohio (No. 183, F. C. 59.79), or

<sup>a</sup> Allowing for low sulphur in the western coals here mentioned. See No. 141 (F. C. 61.49), No. 199 (F. C. 61.23), and No. 100 (F. C. 59.39).

Darby, Va. (No. 217, F. C. 59.60). In the lower grades of bituminous coals the Cretaceous and Tertiary samples apparently have slightly higher volatile-carbon ratios as compared with the H:O ratios than the Paleozoic coals of the same rank. This may be due to the amount of resin in most of the former. Under advanced devolatilizing influences the resin appears to be transformed, possibly to disappear in the volatile.<sup>a</sup>

#### DISTINCT CATEGORIES IMPOSSIBLE.

Plate III in connection with Table 2 conclusively shows the futility of looking in the ultimate analyses for characters by means of which coals may be grouped into distinct and natural categories. Such a classification is an impossibility with only the current data. There are no distinct lines of separation of coals into any categories. From the very circumstances of coal formation—the constantly varying ingredients, conditions of accumulation and deposition, and relations and intensities of the processes—it is evident a priori that between each type and any other type there must be, since coal is merely a mixture of chemical compounds, every degree of intergradation. The classification of coals on the basis of their chemical analysis must therefore be absolutely arbitrary, with very finely drawn as well as purely empirical distinctions.

#### COMPARISON OF TYPES.

The discrimination between lignites and subbituminous coals presented in Table 1, which agrees with Campbell's classification (see p. 10), has the great merits of simplicity and naturalness of grouping, readiness of application, and practical freedom from technical criteria. It is the only kind of classification that is adapted to common usage. Yet the difficulties due to the transitions from group to group are not less real and perplexing. Neither is it strange that, being based on physical characters and weathering criteria, it does not conform wholly to the conditions indicated by the analyses.

The fixed carbon column of Plate III shows conspicuously a somewhat indiscriminate mingling of lignites (L), subbituminous coals (S), and low-grade bituminous coals. In the ratio columns the intermingling of lignites and subbituminous and bituminous coals appears to be limited to border zones, the more important transgressions being those caused by weathering of the coals.<sup>b</sup> So far as present analyses are competent to serve as a basis for calculations it seems that in most coals the H:O ratio may provisionally be regarded as ranging up to 22 in the peats; from 22 to 29 in the lignites (brown coals);

<sup>a</sup> Additional field observations are needed on this point.

<sup>b</sup> No. 2b (F. C. 50.53) is weathered.

from 28 to 38 in subbituminous coals; and from 31 upward in the younger low-grade bituminous coals, or from 40 upward in the Paleozoic coals. The ratios, as may be noted in Plate III, do not all fall within these limits; but it is believed that additional data (which are much needed) will show that they fall generally within the limits here provisionally outlined. The lowest ratio for a Paleozoic coal in the table is 38.3 for a Zeigler analysis (F. C. 62.74). Mr. Campbell's classification is thus seen greatly to lower the under limit of the bituminous category, so as to include therein a large number of coals which are much less advanced in the coal-forming process than the lowest grade of the American Paleozoic coals.

It is well known that the coals of certain districts exhibit characteristics peculiar to the district or perhaps to their kind. For example, the xyloid lignites of North Dakota are in general marked by low H:O ratios; the Kootenai coals of the Great Falls field have comparatively low hydrogen and carbon in their volatile, and consequently low H:O ratios, though, on account of the great amount of charcoal, their fixed carbon is as high as that of many of the fine coking coals of the Appalachian trough;<sup>a</sup> but it is also true that the differences due to geologic period are, in coals of the same initial classes of ingredient matter and conditions of biochemical action, obliterated, so far as may be seen in the ultimate analysis, by dynamic influences expressed in metamorphism and progressive devolatilization

#### OBLITERATION OF DISTINCTIONS AS A RESULT OF REGIONAL METAMORPHISM.

Comparative examination of the coals assembled in the accompanying tables shows most convincingly the efficient work of the dynamochemical processes in wiping out all the important distinctions due to differences in the age of the fuel. Under this action the coals of all epochs undergo essentially the same experience of progressive devolatilization, deoxygenation, and concentration, though not without great waste, of carbon and hydrogen. The closeness of the agreement between the corresponding advanced stages of the older and the younger coals is shown by their industrial adaptation as well as by the ultimate chemical analysis. The high-grade coking coal and semianthracite of the western Upper Cretaceous and Tertiary formations are as truly coking and semianthracite as though they had grown in the vast umbrageous swamps of the Paleozoic. The brown coals of North Dakota are progressively transformed to semi-bituminous and to bituminous as they extend farther within the regions of the increased geodynamic action which effected the further upthrust of the Rocky Mountains. The Cretaceous coals of

---

<sup>a</sup>Compare No. 73b (F. C. 64.39); No. 44b (F. C. 65.74); and No. 25a (F. C. 65.91).

the Crested Butte, Colo., region are transformed to semibituminous coking coals and to anthracites under dynamic influences, the chief of which is, I believe, horizontal thrust pressure under loading. Only very rarely, and in very restricted localities, is the metamorphism due to plutonic intrusives or overflows.

To a limited but convincing extent these changes may be followed in the same bed as well as in the same geologic formation and region. It appears only to be necessary that the coals be of the same kind at the beginning in each case. If xyloid lignites they become xyloid bituminous coals; if cannel brown coals they become bituminous cannels, etc. There appears to be no important difference in mode of formation or composition between the Upper Cretaceous cannel coals near Cedar Valley in Utah and those of the upper Pottsville in eastern Kentucky. The dull, dense, "amorphous" bands, sometimes approaching a bastard cannel, which may not infrequently be observed in the Paleozoic coals of the Appalachian trough, are both in their nature and in the conditions of their formation exactly like those similarly found in the Cretaceous and Tertiary coals and in the Pennsylvania anthracites. The differences, principally relating to the degree of elimination of the oxygen content, mark the progress of the dynamochemical work in the process of coal formation.

## OXYGENATION AND WEATHERING OF COALS.

### CHANGES IN LOW-GRADE COALS.

Both in connection with the discussion of the causes of variance from the C:(O+ash) ratio and efficiency curve, and in the review of the comparative standing of the H:O ratios in Plate III, it has been noted that in general the lower classes of coals take oxygen on exposure to the atmosphere. This, together with some immediate loss of compressed volatile matter, appears to mark the first phase of weathering. Later, and on prolonged exposure, there seems to be considerable loss of carbon and hydrogen also, especially in the humic (ordinary) coals.

### EFFICIENCY LOSSES IN WEATHERING.

The consideration of this subject engages us only in so far as it obviously affects the efficiency of the ratio curve. The analytical data now available in the reports of the coal-testing work are unfortunately deficient as to such samples and localities as alone will put in the hands of geologists and engineers the data necessary for knowing the total efficiency losses endured by some of our thinly covered or long mined, not to mention weathered, coals. An inquiry to show the kinds, degrees, and rapidity of loss under varying conditions would require a large number of ultimate analyses; but I am

confident that the results of a series of such observations would in many cases prove surprising as well as important.

The amount of oxygen that is assimilated and the rapidity with which it is taken up by certain subbituminous coals and lignites seem to indicate very unstable chemical conditions in the combustible matter of these coals as they lie deeply buried in the strata. It will later be seen that in some coals the amount of this absorbed oxygen exceeds the capacity of the hydrogen to form water.

#### LOSSES SHOWN BY ANALYSES AND RATIO-EFFICIENCY CURVE.

Mention has been made of the almost invariable calorific deficiency, as indicated by the curve, of those coals that have been weathered, taken from shaly or thinly covered mines, or country banks, or deep but abandoned mines. Most of these coals are from geologic formations or regions in which the coals are exceedingly low in sulphur, so that many of them should show excess curve errors if wholly unaffected; and this seems to be borne out by some of the better samples from the same districts. The few comparisons given below are offered rather as suggestions and as bases for rough estimates than as careful calculations based on representative, not to say ample, material.

Following are the analyses of two coals from the Lewis (Cretaceous) shale, 22 and 24 miles northwest of Fort Steele, Wyo. The coal is subbituminous. The first, No. 53a of Table 1, is from an entry near the foot of the shaft; the second was taken near the surface of the ground.

#### *Comparison of two coals to show effect of weathering.*

No.	S.	H.	C.	O.	Ash.	Moisture.	F. C.	H:O.	Av. H.	Calories.	Curve error.
53a.....	0.85	5.16	63.57	22.05	3.80	8.70	55.36	24.2	2.02	6,310	+ 30
Wyo. 3919 <sup>a</sup> ....	.31	4.90	59.86	29.39	4.12	9.34	55.57	18.3	1.23	5,636	-219

<sup>a</sup> Bull. U. S. Geol. Survey No. 316, 1907, p. 256.

The second of these analyses does not differ widely from the first if the first be recalculated after adding 10 per cent of oxygen. The difference in calories between the two analyses is 674. If a lump allowance of 50 calories is made for difference in ash, etc., in the second, we shall have left 624 calories as a rough estimate for the loss in weathering. In this case the loss would be about 62 calories for each 1 per cent of added oxygen. This is not far from the actual antic calorific value of oxygen in a coal having the same C:(O+ash) ratio as 53a. The effect of the added O is seen both in the reduced H:O ratio of the weathered specimen and in the VC:C ratio, which in the weathered is 19.48 as compared with 23.80 in the shaft coal. The fact that adding 10 per cent of oxygen to No. 53a creates a

small deficiency in the hydrogen, the carbon, and the H:O ratio, as well as in the available hydrogen, indicates either some loss of carbon and hydrogen in the deteriorated sample or that the absorbed oxygen is a little under 10 per cent, possibly as low as 7 per cent.

It will be borne in mind that the ratio-efficiency curve errors, which show large deficiencies in these deteriorated coals, may represent but portions of the real calorific losses; for the added oxygen has naturally had the effect of lowering the C: (O + ash) ratios, thus placing them lower in the curve. It is interesting to note, however, that the calorimetrically ascertained efficiencies of these weathered coals generally exceed those calculated by Du Long's formula.

#### LOSSES SHOWN BY H:O AND VC:C RATIOS.

Evidence of the effects of exposure or weathering is often obvious in the ratios as well as in the calorific deficiencies. This is represented graphically in Plate III. Usually the drop is more conspicuous in the VC:C ratios as here tabulated. Examples of coals from prospects whose ratios are to be interpreted as indicating deterioration are No. 62a (F. C. 61.62) and No. 72a (F. C. 60.89), both being bituminous coals. The subbituminous coal at Fall River, Wyo. No. 9a (F. C. 41.22), is placed among the brown coals below the other subbituminous coals in Plate III, as the result, I believe, of exposure.

A striking illustration of profound deficiencies in both ratios is seen in No. 2b, a subbituminous coal from the Labarge Range, Wyo. (F. C. 50.63), in which the H:O ratio is but 11.1, while the VC:C ratio is only 17.47. More remarkable still, there is a deficiency of 0.37 in the hydrogen necessary to form water in union with the oxygen of the coal. It therefore seems probable that part of the oxygen in this coal exists as CO, CO<sub>2</sub>, or atmospheric oxygen. The table contains three other analyses (Nos. 55a, 44a, and 39a) from the same formation and district. The four analyses are repeated below.

*Comparison of coals from same district, to show effects of weathering.*

No.	S.	H.	C.	O.	Ash.	$\frac{C}{O+ash}$
55a	0.84	5.68	63.81	25.75	2.84	2.23
44a	2.10	5.74	61.76	25.96	3.41	2.10
39a	1.14	5.39	62.05	24.56	5.77	2.04
2b	.61	4.45	48.65	38.57	6.87	1.07

No.	Moisture.	F. C. in pure coal.	VC:C.	H:O. <sup>a</sup>	Av. H.	Calories.	Curve error.
55a	10.22	53.81	27.94	28.6	2.46	6,558	- 43
44a	10.78	52.06	28.85	29.0	2.50	6,057	-140
39a	9.02	56.51	23.37	27.4	2.32	6,039	- 90
2b	13.83	50.63	17.47	11.1	- .37	4,468	-150

<sup>a</sup>The H:O ratio is calculated on the moisture-free basis.

Nos. 55a and 39a are from drifts, and, although probably somewhat affected by influences from the surface, are relatively fresh. No. 44a, as might be suspected from its marked deficiency error, is from a prospect. It is presumably either deeper or newer than No. 2b, which is also from a prospect, since it shows less change from the composition of the deeper coals.

Since No. 39a, the third coal of the series, appears to agree in its main criteria with No. 2b, and since it may be, perhaps, safely regarded as not seriously weathered, it will be taken for comparison with the latter. A glance at the two analyses shows that the important differences between these coals concern the oxygen, the available hydrogen, and the calorific values. Examination of these differences makes it evident that if a little over 20 per cent of oxygen be added to that in No. 39a and the analysis of the latter be then recalculated to 100 per cent, the resultant percentages will fall reasonably close to the corresponding elements in No. 2b without further compensation. It therefore seems probable that the prospect coal in a less weathered state was essentially like that of the drift coal, No. 39a. The increase in oxygen was, perhaps, nearer 25 per cent. The accession of that amount of oxygen closely corresponds to the difference in the calorific values of the two coals, which amounts to 1,571 calories—that is, nearly 65 calories to each 1 per cent of added oxygen. This agrees closely with the ascertained anticalorific value of oxygen in a coal having a C:(O+ash) ratio near 2.00. Compensation for the difference in moisture, etc., in the coals seems to justify the conclusion that over 20 per cent of added oxygen has entered into combination with the fuel elements of the weathered coal.

It will also be observed that the assimilation of 20 per cent of oxygen in a coal like No. 39a will accomplish a little more than the extinction of its available hydrogen, causing a deficit of 0.18 in the amount necessary to form water. On the other hand, the elimination of 20 per cent of the oxygen in No. 2b, the weathered coal, will make available 2.13 per cent of hydrogen, which, if the analyses be recalculated to 100 per cent, will approach still closer to that of the other analyses.

Thus, in short, the evidence drawn from (a) the comparison of the analyses of the more with the less weathered fuel, (b) the probable loss in calorific value, and (c) the amount of the reduction of available hydrogen agrees in indicating a probable assimilation of 20 per cent or more of oxygen in the course of weathering. All things considered, it is perhaps safe to estimate the falling off in the efficiency of this subbituminous fuel at nearly one-fourth of its original heating power in the calorimeter.

The sample just discussed on account of its availability among the analyses studied in the preceding pages is not to be regarded as extraordinary or even unusual among weathered coals of its class. More strongly marked hydrogen deficiencies and more conspicuous degradations are to be found among the field samples.<sup>a</sup> Analyses of surface samples of coals of these grades are of little value in determining the characteristics of the coal, except in so far as they indicate the approximate amounts of sulphur and ash. Many of the analyses of coals from deep prospects and country banks are not to be taken as showing the real merits of the fuel.

It appears that in the lignites (brown coals) the deterioration is still greater; and it follows, almost as a certainty, that in some of the peats, particularly among the xyloid or more fibrous types, the loss of calorific value during the periods of drying, manufacture, and storage—that is, between the moment of exhumation from the pit bottom and the time of deposition in the crucible or on the grate—may be very serious. It may not be extreme to suggest that this loss possibly amounts in certain cases to as much as that incurred through weathering in some of the subbituminous coals.

#### UNDERGROUND WEATHERING.

The analyses bear evidence, according to my tentative interpretation, that the phenomena of weathering are not confined to outcrops or shallow prospects. There are a number of coals in which I suspect oxygenation to have taken place to some extent in shallow mines or country banks and drifts which have not penetrated too far from the surface. An example of these is No. 2a from near Miles, Mont.<sup>b</sup>

A sample showing what I am inclined to interpret as oxygenation as the result of exposure to air for a long period in a large mine of good depth comes from the No. 6 mine at Rock Springs, Wyo. This mine is said to have been abandoned about ten years ago. The coal is subbituminous and of high quality, as will be observed from the analysis.<sup>c</sup>

Below is given, from Table 1, the analysis (air-dried basis) of No. 144, the coal from No. 10 mine at Rock Springs, Wyo., as in car sample at the fuel-testing plant of the United States Geological Survey; and following it the analysis from the abandoned No. 6 mine, recalculated to the same percentage of moisture as No. 144.

<sup>a</sup> See analyses published in Bull. U. S. Geol. Survey No. 316. Examples are Wyoming 3695 and 3697, p. 237.

<sup>b</sup> See also No. 4a from near Glendive, Mont.; Nos. 175a, 166a, 146c, 72a, and 62a.

<sup>c</sup> Analysis included by courtesy of Mr. M. R. Campbell.

*Comparison of coals showing effect of long exposure to air in abandoned mine.*

No.	N.	S.	H.	C.	O.	Ash.	Moisture.	Calories.	H:O.	Av. H.	VC:C.	F.C.
144.....	1.52	0.86	5.37	70.30	18.32	3.63	6.00	6,955	36.2	3.08	26.49	57.19
Wyo. 6042.	1.46	.46	5.01	66.32	22.03	4.72	6.00	6,340	26.1	2.23	15.41	62.88

If to sample 144, from the active mine, we add 5 per cent of oxygen and recalculate to a basis of 100 per cent, compensating the calorific value, we have:

*Recalculation of analysis of sample 144.*

Nitrogen.....	1.45	Ash.....	3.46
Sulphur.....	.82	Moisture.....	5.71
Hydrogen.....	5.11	Calories.....	6,624
Carbon.....	66.95	H:O ratio.....	26.3
Oxygen.....	22.21	Available hydrogen.....	2.33

This analysis, as will at once be recognized, approaches substantially that of the sample from the abandoned mine. In nitrogen, carbon, and hydrogen the agreement is satisfactorily close, as is also the amount of available hydrogen, which becomes 2.33 compared with 2.23. In fact, the agreement between the recalculated No. 144 and the abandoned-mine analysis is sufficiently close to justify the conclusion that, together with the other presumable changes, 5 per cent or more of oxygen had probably been assimilated in the coal deep in the old mine on account of exposure to air since its abandonment. The difference in the calorific value is disproportionate to that which might reasonably be expected from the mere addition of 5 per cent of oxygen, and offers ground for the suspicion that there has been a small loss in carbon and hydrogen. The calorific difference, roughly compensated for difference in ash and sulphur, amounts to about 535 calories, or about 105 to each 1 per cent of assumed oxygen increase. This, as shown on page 40, is probably as much as 10 calories in excess for added oxygen.

It is probable that in the subbituminous coals, and more especially in the lignites, oxygenation begins immediately after the coal is blasted from the face in the mine. Zincken<sup>a</sup> quotes Bischoff to the effect that the brown coal of Pützchen absorbed 11 per cent of oxygen from the atmosphere in eight days. More recently Stremme and Späte<sup>b</sup> have shown some absorption even by sapropelic coals standing for various periods in a museum. It should be noted, however, that the sapropelic or alga coals are very much less susceptible to oxidation on exposure than are the more bituminous coals, which are humic.

<sup>a</sup> Physiographie der Braunkohlen, 1867, p. 8. See also Muck, Chemie der Steinkohlen, 1891, p. 109.

<sup>b</sup> Zeitschr. angew. Chemie, vol. 20, pt. 43, 1907, p. 1841; also Zeitschr. Deutsch. geol. Gesell., Monatsber., Nos. 7 and 8, 1907.

It is not impossible that some of our peats will be found to assimilate still greater quantities of oxygen on exposure. This question, as well as that of the immediate loss of volatile in freshly mined lignites or subbituminous coals, is one deserving careful examination. The results of the very interesting, as well as important, investigations recently published by Parr and Hamilton,<sup>a</sup> show that deterioration is strongly marked and rapid, even within short periods, in coals so old and well established in coal formation as those of the Illinois region, where an efficiency of 2 to 10 per cent may be lost on exposure for seven months. A still greater susceptibility to change is, I believe, to be expected in the higher-grade bituminous coals of some portions of the western Mesozoic and Tertiary coal fields, in which the dynamic influence is still in vigorous action, locally at least, as shown by rapid loss of volatile, and in which, on account of lack of time in which the volatile might effect its escape (with concomitant readjustment of compounds to comparative equilibrium in conformity to the new conditions), it may be assumed that the hydrocarbon compounds are in a state of highly unstable equilibrium. The susceptibility to deterioration is doubtless far greater in many of the subbituminous coals and lignites.

#### LOSSES BY WEATHERING IN SHIPMENT.

A comparison of the calorific values of the car samples with the ratio curve on the one hand and with a few mine samples collected by the field geologists on the other, seems to me to warrant the apprehension that in some samples at least a considerable deterioration has occurred before the actual analysis of the fuel. My personal opinion, based upon quite insufficient data, is that the car samples of most of these lignites and of many of the subbituminous coals are calorifically deficient to an extent of 50 calories as compared to the probable efficiency of freshly mined and tightly sealed mine samples, provided the latter are analyzed immediately upon opening. It may not be overhazardous to estimate that some of the published calorific values are as much as 200 calories less than the efficiency of the coal in the ground. The coal No. 51a, from Batan Island, P. I., may be mentioned as a good example of probable loss between the coal bed and the crucible. Analyses Nos. 3, 13, 19, 22, 32, 56, 83, and 144 also appear to justify suspicion.

The amount of loss depends not only upon the kind of coal, but also on the conditions of loading, the kind of car, the size of the fragments, the weather, the period of transit (which for many coals is over three weeks), and the mode of sampling from the car. The present method of air drying the coal in an oven under a current of

<sup>a</sup> Econ. Geology, vol. 2, 1907, p. 693.

warm air in the laboratory may also be mentioned as seeming most favorable to the oxygenation of the fuel and its consequent rapid calorific deterioration.

For commercial purposes the current methods of sampling and analysis appear to be very satisfactory and even indispensable, since they show the composition of the coal as it is ordinarily received at its industrial destination. Yet it is possible that a thorough investigation of the impairment of the lowest-grade fuels on exposure will show a calorific loss in some coals that is so great within a short time as perhaps to call for new methods of handling.

The above observations, it must be remarked, are disconnected and fragmentary, and crude both as to methods and results. Their purpose is mainly to stimulate observation. I anticipate, however, that properly made tests and careful calculations, based on adequate data, will show the importance of the subject to have been on the whole understated.

#### SUMMARY.

1. Coals with high oxygen and low ash will, in general, have very nearly the same efficiency in the calorimeter as other coals with alternated percentages, low oxygen and high ash, if the total carbon is the same. This applies to both air-dried and moisture-free coals.

2. Oxygen and ash are of very nearly equal anticalorific or negative value, ash being probably slightly more injurious in most coals; the negative value of the oxygen of moisture is not far different from that of the oxygen combined in the coal.

3. The calorific value of coals in general is essentially indicated by the balance between the total carbon, on the one hand, and the sum of the two great impurities, oxygen and ash, on the other, the hydrogen, nitrogen, and sulphur being usually negligible as "constants."

4. Except in the presence of unusual variations of hydrogen or sulphur, the efficiencies of the coals, if ash be constant, rank nearly in the order of the ratios C:O, which in each kind of coal marks the progress of coal formation under dynamochemical influences.

5. Oxygen and ash being of approximately equal anticalorific potency the efficiencies of the coals conform fairly closely to the order of the ratios C:(O+ash), so that among coals of all kinds those having the same ratios are found to have not far from the same efficiency. The causes of the greater departures are mentioned in the next paragraph.

6. A miscellaneous series of coals of all kinds, ages, and regions, when platted according to the C:(O+ash) ratios and calorific values as components, describe a curve to which they conform very closely, the average variance being less than 1 per cent of the calorific value. The greatest variances are among (a) weathered coals, (b)

those having 79 per cent or more of fixed carbon in pure coal—that is, those undergoing anthracitization—and (c) the boghead-cannel group, in which the hydrogen is excessively high, so that the efficiencies describe a higher curve characteristic of the group.

7. The departures from the ratio-efficiency curve on account of unusually high or low available hydrogen are generally not large. High sulphur is usually attended and compensated by high hydrogen, the converse being true to a less extent. Unusually high sulphur acts, on the whole, as a diluent, while very low sulphur leaves the relative field to the heat-determining elements. Consequently the variances from the curve on account of the neglected constants—hydrogen, sulphur, and nitrogen—are rarely over 2 per cent unless in the exceptions noted in paragraph 6.

8. Types of coals are initially determined by the nature of the ingredient matter, the conditions of deposition, and the extent of operation of the first or biochemical process in coal making; but progressive devolatilization, lithification, cleavage, and other accompanying alterations result from the second or dynamochemical stage of coal formation, which in each kind removes the essential distinctions of age or region, even tending ultimately to obliterate the differences in kind. Consequently any classification of coals based on the present form of ultimate analyses must be arbitrarily defined. There is intergradation in all parts of the process of coal conversion and coal alteration, as well as in the ingredient matter and conditions of deposition.

9. The weathering of the lower grades of coal, especially the lignites, bituminous coals, and peats, is marked by the accession of oxygen, which is taken into combination. This increase of the oxygen contents, which seems to indicate lack of equilibrium in the hydrocarbon compounds of the normal coal, readily permits a calorific deficiency, which, on account of the high anticalorific value of oxygen, is often serious. It is possible that in many cases considerable increase of oxygen and consequent loss of efficiency are suffered by the lower-class fuels between removal from the bed and deposit in the grate or the chemical crucible.

10. The adaptability of a coal to coking by the ordinary process appears to be indicated with a fair degree of certainty by the ratio of the hydrogen to the oxygen, moisture-free basis. Practically all coals with H:O ratios of 59 (per cent) or over seem to possess the quality of fusion and swelling necessary to good coking. Most coals with ratios down to 55 will make coke of some kind, while a few coals with ratios as low as 50 coke in the beehive oven, though very rarely producing a good article. The coking property seems to depend, not so much on the amount of available hydrogen, which is a very imperfect index of the proportion of the elements in the

volatile, but on the relative amount of the hydrogen as compared to that of the oxygen. In those coals undergoing change to anthracite, the hydrogen-oxygen ratio may fail as a guide; the failures appear, however, to be readily distinguished by the marked calorific deficiencies shown by the C:(O+ash) ratio and efficiency curve. The data examined, though insufficient to serve as a basis for a conclusion, seem to point toward the need of a relatively high carbon element in the remaining volatile combustible of coals with 79 per cent or more of fixed carbon (pure coal), in order to secure either the best coking results or the calorific efficiency indicated by the C:(O+ash) ratio-efficiency curve.

## PARTIAL BIBLIOGRAPHY.

### SURVEY PUBLICATIONS ON COAL.

A bibliography of United States Geological Survey publications containing references to coal is given in Bulletin 341, Contributions to Economic Geology, 1907, part 2, pages 419-436. The following publications treating of the work of the Survey fuel-testing plants contain many analyses of coals. The Survey's supply of those designated by an asterisk is exhausted, but they can be purchased from the Superintendent of Documents, Government Printing Office, at the prices named. Copies of the others can be obtained free by applying to the Director of the Geological Survey.

BULLETIN 261.\* Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp. 10 cents.

PROFESSIONAL PAPER 48.\* Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. In three parts. 1492 pp., 13 pls. \$1.50.

BULLETIN 290.\* Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp. 20 cents.

BULLETIN 323.\* Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 1907. 49 pp. 10 cents.

BULLETIN 332. Report of the United States fuel-testing plant at St. Louis, Mo., January 1, 1906, to June 30, 1907; J. A. Holmes in charge. 299 pp.

BULLETIN 336.\* Washing and coking tests of coal and cupola tests of coke conducted by the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to June 30, 1907, by Richard Moldenke, A. W. Belden, and G. R. Delamater, with introduction by J. A. Holmes. 1908. 76 pp. 10 cents.

BULLETIN 362.\* Mine sampling and chemical analyses of coals tested at the United States fuel-testing plant, Norfolk, Va., in 1907, by J. S. Burrows. 1908. 23 pp. 5 cents.

BULLETIN 363. Comparative tests of run-of-mine and briquetted coal on locomotives, including torpedo-boat tests and some foreign specifications for briquetted fuel, by W. F. M. Goss. 1908. 57 pp., 4 pls.

BULLETIN 368. Washing and coking tests of coal at Denver, Colo., by A. W. Belden, G. R. Delamater, and J. W. Groves. 1909. 54 pp., 2 pls.

## MISCELLANEOUS RECENT PUBLICATIONS.

The following books and papers treat of the composition of coals:

1905.

- DONATH, ED., Betrachtungen über das Backen und über die Bildung des Steinkohle, Oesterr. Zeitschr. Berg. und Hüttenwesen, January 11, 18, 25.  
 FULTON, J., Coke, A treatise on the manufacture of coke and other prepared fuels. Scranton.  
 POTONIE, H., Die Entstehung der Steinkohle und verwandter Bildung einschliesslich des Petroleums. Berlin. 45 pp.

1906.

- BEMENT, A., The sampling of coal. Jour. Am. Chem. Soc., vol. 28, pp. 632-639.  
 CAMPBELL, M. R., The classification of coals. Trans. Am. Inst. Min. Eng., vol. 36, pp. 324-340.  
 FRAZER, PERSIFOR, The classification of coals. Trans. Am. Inst. Min. Eng., vol. 36, pp. 825-833.  
 PARR, S. W., Composition and character of Illinois coals. Bull. Illinois State Geol. Survey No. 3.  
 ——— The classification of coals. Jour. Am. Chem. Soc., vol. 28, pp. 1425-1432. Also Mines and Minerals, December.

1907.

- DIRKE, H. B., Illinois coal tests. Eng. Record, February 25.  
 GREENWELL, A., and ELSDEN, J. V., Analyses of British coals and coke and the characteristics of the chief coal seams worked in the British Isles. London. 405 pp.  
 GROUT, F. F., The composition of coal. Econ. Geology, April-May, pp. 225-241.  
 HEADDEN, W. R., A study of some Colorado coals. Proc. Colorado Sci. Soc., vol. 8, pp. 281-300.  
 KEIGHLEY, F. C., Why do some coals coke? Mines and Minerals, October.  
 MACCALLUM, H., The classification of coal. Canadian Min. Jour., May 1.  
 MUCK, F., Die chemie der Steinkohle. Leipzig. 66 pp.  
 PARR, S. W., Heat production and the constituents of coal. Eng. and Min. Jour., June 29.  
 PARR, S. W., and HAMILTON, N. D., The weathering of coal. Econ. Geology, October-November, pp. 692-703.  
 ——— The weathering of coal. Bull. No. 17, Univ. Illinois Eng. Exper. Sta., 37 pp.  
 POTONIE, H., Historisches zur Frage nach der Genesis der Steinkohle. Naturw. Wochenschr., vol. 6, pp. 113-117.  
 WOODMAN, J. E., Coal sampling. Canadian Min. Jour., May.

1908.

- CAMPBELL, M. R., A practical classification of low-grade coals. Econ. Geology, March-April, pp. 134-142.  
 DOWLING, D. B., Classification of coals by the split volatile ratio. Canadian Min. Jour., April 15, pp. 143-146.  
 FISHEL, M. A., A practical test for coking coal. Econ. Geology, June-July, pp. 265-270.  
 PORTER, F. C., and OVITZ, F. K., The nature of the volatile matter in coal as evolved under different conditions. Jour. Am. Chem. Soc., vol. 30, pp. 1486-1507.  
 WHITE, DAVID, Some problems in the formation of coal. Econ. Geology, June-July, pp. 292-318.