GEOLOGICAL SURVEY OF MICHIGAN

ALFRED C. LANE, STATE GEOLOGIST

VOL. VIII

PART II

COAL

OF

MICHIGAN

ITS MODE OF OCCURRENCE AND QUALITY

BY

ALFRED C. LANE

ACCOMPANIED BY NINE PLATES AND NINE FIGURES
INCLUDING ONE COLORED MAP

PUBLISHED BY AUTHORITY OF THE LAWS OF
MICHIGAN
UNDER THE DIRECTION OF
THE BOARD OF GEOLOGICAL SURVEY

LANSING
ROBERT SMITH PRINTING CO., STATE PRINTERS AND BINDERS
1902

OFFICE OF THE STATE GEOLOGICAL SURVEY,
LANSING, MICHIGAN, July 17, 1901.

To the Honorable, the Board of Geological Survey of Michigan:

HON. A. T. BLISS.
HON. LINCOLN AVERY.
HON. DELOS FALL, *Secretary.*

GENTLEMEN—Herewith I transmit as Part II of Vol. VIII, a report by myself, containing the results of my examination of the coals of the State in a general way.

Although it does not pretend to be exhaustive in its description of the wealth of the State in this particular material it seems to me that it may help give some idea as to the known variations in quality, which is better on the whole than has been reported, may help those who desire to test the quality to do so to best advantage, may give some idea of what has been done, and yet remains to be done in testing, and may save some useless exploration. If I have given especial attention to the probable depth to which it is worth while to test and have depicted the hindrances quite fully it must be remembered that forewarned is forearmed. I have not attempted to trespass on the field of the Commissioner of Mineral Statistics, and the Coal Mine Inspector, Mr. Wm. Atwood, whose valuable reports are made at frequent intervals to the Labor Commissioner, except so far as it has been necessary to use the facts gathered by them in studying problems proper to economic geology.

The records herein given of test borings are reported to us, and I do not guarantee their accuracy. I think that so far as they throw light upon the area and thickness of the coal series as a whole they may be trusted.

Not so much reliance can be placed upon the indications for individual beds, but in any case these can vary much in a few yards.

With great respect I am your obedient servant,

ALFRED C. LANE,
State Geologist.

TABLE OF CONTENTS.

CHAPTER I.

INTRODUCTION.

CHAPTER II.

ORIGIN OF COAL.

CHAPTER III.

OCCURRENCE OF COAL.

CHAPTER IV.

ANALYSES AND TESTS OF COAL.

CHAPTER V.

THE EROSION AND DISTURBANCE OF COAL.

CHAPTER VI.

THE DEVELOPMENT OF COAL.

CHAPTER VII.

DEVELOPMENTS AND BORINGS ARRANGED BY COUNTIES.

LIST OF ILLUSTRATIONS.

PLATES.

FIGURES.

ERRATA,

Not Including Mistakes of Capitalization.

Page 28, line 1 from below, read W. F. Ward.

Pages 37, 175, 176. I have carelessly mixed up in my use the names of two prominent Saginaw men. Dr. H. C. Potter was president and superintendent of the East Saginaw Salt Mfg. Co., which put down the first well, but Dr. Geo. A. Lathrop was one of the promoters and kept the record.

Page 39, line 23 from above, for 57 read 5.

Page 43, line 5, for Discinesca here and elsewhere read Orbiculoidea, which has also been found at the air shaft of the Michigan mine at St. Charles and identified by Mr. Girty as O. missouriensis.

Page 54, line 16, before 650 read + instead of ×.

Page 91, line 13 below, read analysis.

Page 105, line 3 from below, read July 23.

Page 166 is misnumbered 66.

Page 168, line 2 from below, strike out comma after Bangor.

Page 185, line 22 read O'Donnell and Spencer Co.

Page 186, line 13 for W.: read E.:

Page 202, line 25, for Milletts read Millett.

CHAPTER I.

INTRODUCTION.

§ 1. Object and history of this report.

This report was prepared in the fall of 1898, at a time of rapid development in the Michigan coal basin, to anticipate and help that development. Its primary object was to give the land owner of Lower Michigan that amount of geological information which would enable him to form an intelligent estimate of the value of his land for coal mining purposes, and to plan intelligently for the economical development thereof. As it could not be published by the Board when prepared, the Board authorized the Michigan Miner to print it serially. The publisher thereof furnished 500 reprints. As these are all gone, and the Board has now ampler means for publication, it is proper for the State to reprint the same in uniform style with the other publications of the Board, for the previous publication cannot be regarded as official.

At the same time the opportunity to bring the report up-to-date has been used, and the discussion of the heating values of our coal has been made far more full, and new formulæ, derived from our analyses, computed for estimating the relative heating value from the proximate as well as the ultimate analysis, and from the reducing power of the coal.

The discussion of the correlation of the coal seams is also extended a good deal and a brief summary of explorations so far as made public is offered.

It was prepared in accordance with that paragraph of the act establishing the Geological Survey that provides for "condensed statements, * * * as often as possible, * * * of important and interesting facts for general circulation," and is deemed advisable and timely, in view of the recently quickened interest in the coal deposits of the Saginaw Valley, and the rapidly increasing production of coal.*

---

*Revised Laws (1523), Title V, Part V, Chapter 55, Sec. 6.

The hour came when the "inexhaustible supplies of pine" of the Saginaw Valley were practically exhausted. It was no longer necessary to burn slabs to get rid of them. The price of coal imported from Ohio and Pennsylvania was no longer subjected to this healthy competition. This meant that for the continuance of the salt manufacture, and growth and continuance of other industries, a cheap fuel must be found to take the place of slabs. The economic hour struck when the supplies of coal more or less known for fifty years, and outlined by the geologist many years ago, were to be utilized. This development began in 1895.

§ 2. Comparative development in other States.

But, as we shall see, the abundance of cheap wood combined with other and peculiar difficulties to retard the development of the Michigan coal basin in comparison with that of other States. In the intervening years neighboring States have made tenfold the output that we have. Now that we do need to develop our resources, we may have the benefit of their experience if we will, and we shall be foolish if we do not avail ourselves of it. For there are certain rules as to the way coal occurs that have proven so widely true, that they may be expected generally to hold true in the future, though, as for all rules, we may expect some exceptions. In thus drawing on the experience of other regions I shall use especially States lying near by in the Mississippi Valley, and recently studied, examined and reported upon, to wit, Ohio, Missouri, Iowa and Indiana. I shall lay down a rule which I take to be applicable to the occurrence of coal in Michigan, shall state briefly some of the facts that indicate that the rule applies in this State, and then cite the authorities that declare the rule to hold true elsewhere also.*

---

*For Iowa, Iowa Geological Survey, Vol. II, by Chas. Rollin Keyes, Des Moines, 1894, hereafter cited as Keyes, Iowa, 1894; also Vol. VII, Annual Report for 1896, with accompanying papers, Des Moines, 1897, especially pp. 263-413, "Geology of Polk County," by H. F. Bain, cited as Bain, Iowa, 1897; also an article by H. F. Bain in the Journal of Geology, published by the University of Chicago, Vol. III, p. 646.

For Ohio, of the Reports of the Geological Survey, Columbus, Ohio, especially, Vol. V, Economic Geology, pp. 1-300 and 773-1089, cited as Orton, Ohio, 1884; also Vol. VI, Economic Geology, Columbus, 1888, cited as Orton, Ohio, 1888; also Vol. VII, Economic Geology, Norwalk, 1893, pp. 255-290, cited as Orton, Ohio, 1893.

For Missouri, Preliminary Report on the coal deposits of Missouri, by A. Winslow, Geological Survey of Missouri, Jefferson City, 1891, cited as Winslow, Mo., 1891. In this work on p. 31 is a useful list of further references, and Mr. Winslow published much the same general account in the Bulletin of the Geological Society of America, Vol. III, 1892; pp. 109-121, cited as Winslow, 1892.

For Indiana, the 23d Annual Report of the State Geologist, 1898, is a very detailed work.

Both Keyes and Winslow derived much from the older reports of the Pennsylvania Second Geological Survey, under J. P. Lesley, which has made very voluminous publications, and Pennsylvania may be taken as the type State of the Union for the Carboniferous series.

Of particular interest and instruction for us is that by J. J. Stevenson, KKK, Report of Progress in the Fayette and Westmoreland District of the bituminous coal fields of Western Pennsylvania, Part II, the Ligonier Valley, especially

§ 3. Authorities for Michigan.

The foot-note to the previous section has given some authorities outside the State. As regards the Michigan basin, we have the State reports, to wit: The reports of the State Geologist, Douglass Houghton, and his assistants, Bela Hubbard and C. C. Douglass, in 1839, 1840, 1841; the Biennial Report by State Geologist A. Winchell, in 1861; the report by Carl Rominger in 1876 (III of the present series); the report by Wright & Lane in 1895 (Vol. V of the same series); also the reports of the Commissioners of Mineral Statistics (those by C. D. Lawton, 1881-1888 particularly valuable).

Vol. VII, Part II (Huron county), contains a report on the area around Sebewaing. An early private paper and account of practical exploration near Lansing and along the Cedar River, chiefly, is by R. R. Lansing, "Exposition Concerning the Mineral Coal of Michigan," Detroit, 1854. In the Twelfth Annual Report of the Saginaw Board of Trade there are also some analyses of Michigan coal.

Concerning the recent developments we have two pamphlets issued by Mr. C. B. Schaefer. But I have had access to a large amount of unpublished matter. I may note especially an unpublished report by A. Winchell for the Detroit, Grand Rapids & Indiana R. R. on the prospects for coal along their line; a report by S. G. Higgins to the Saginaw Board of Trade on explorations south of that city; most of the original coal mine maps of the Jackson mines, which with other valuable and instructive data I owe to John Holcroft, Esq. Finally, I have also notes of personal visits among other points to Sebewaing, Corunna, Jackson, Rifle River, Owosso, Grand Ledge, Williamston, the valley of the Thornapple, the results of systematic studies and surveys of Huron, Tuscola, Saginaw and Bay counties, and a very large amount of data concerning

---

Chapter II, p. 283. This State also publishes the reports containing Lesquereux's most thorough work on the coal plants. The Pennsylvania reports are cited by capital letters, KKK, P, etc. On the same region, but extending farther south, is Bulletin No. 65 of the U. S. Geological Survey (Washington, 1890), by I. C. White, price 20 cents.

In the Bulletin of the Geological Society of America, Vol. IX, pp. 35-58, is an interesting paper by W. S. Gresley on "Clay veins vertically intersecting coal measures." On the statistics and business of coal, W. J. Nicoll's 'Story of American Coal,' Philadelphia, 1897, and the annual volumes of Mineral Industry, issued by the Engineering and Mining Journal, and the parts devoted to statistics of the Annual Reports of the U. S. Geological Survey may be consulted. On methods of coal analysis and determination see Chapter IV.

The reports of the various State Geological Surveys may be obtained upon application to them at the capital cities above mentioned, and separate reprints of papers published in the Bulletin of the Geological Society of America may be obtained from Prof. H. L. Fairchild, Secretary of the Society, Rochester, New York.

In the Twentieth Annual Report of the U. S. Geological Survey, 1898-99, Part II.—General Geology and Paleontology, there is a paper on the Stratigraphic succession of the Fossil Floras of the Pottsvilie Formation ...., by David White, which is of interest.

borings in various parts of the State which have been collected by the State Survey during the past few years, some of which were collected for a report on the water resources of Lower Michigan, published as Nos. 30 and 31 of the Water Supply and Irrigation papers of the U. S. Geological Survey. I am also deeply indebted to most of the mine managers and many drillers and others for information. But I *have not attempted to give all the facts* upon which the *general* rules summed up in this short report are based, but merely enough to illustrate and make clear their application. Most of the material must, however, be gathered from the daily press or unpublished sources. Of especial interest is the Saginaw Evening News of Saturday, July 23, 1898, "Board of Trade and Coal Development edition."

The statistics are given in the reports of the Labor Commissioner and the Commissioner of Mineral Statistics.

§ 4. Role of the man who wants an option.

The problem of estimating the mineral value of lands, is not easy, and one is quite as likely to over-estimate as to under-estimate it, as the human mind tends to exaggerate the unknown. The following tale has a familiar sound to me: "There was a fellow around here a while ago, who wanted an option on my land, and offered to pay a little cash for it, but I was in no pressing need of money, and I thought if there was anything to be made I might as well make it myself, so that I would wait and see what his explorations showed up. But that was the last I heard of him, and now I am sorry I did not take his money." Compare the fate of coal explorations around Saginaw as recorded in the Standish Independent, December 2, 1898.

There is a tale told of Dr. Rominger, which, whether true or not, illustrates the point, that in the days of the coal excitement on Rifle River along in the '70s he was approached by a homesteader, who wanted to know what his land was worth. "Well," said Dr. Rominger, "Your land is pretty sandy and not very good for farming; if you get $10 an acre you had better take it."

"Ten dollars an acre! Why a man has offered me forty already!"

"Well, didn't you take it?"

"No."

"Well, then, there were two fools instead of one."

The role of the "man who wanted the option," whom for short we call the promoter, is often misunderstood even by himself. He is looked upon as one who has occult knowledge and wishes to take advantage of people's ignorance to beat them out of property, the value of which they do not recognize. This of course he may sometimes do, just as any merchant may over-reach, but he has a legitimate and necessary business, and a useful part to play, even though the land owners knew all there was to be known, or though he told them all that he guessed or knew, as to the present or prospective value of their property. Incidentally we shall show what this legitimate business is.*

---

*See Chapter VI, § 5.

CHAPTER II.

THE ORIGIN OF COAL.

§ 1. From vegetation.

To understand the occurrence of coal, and from our partial knowledge to predict how it will occur, requires some knowledge of its formation.

Without going into the details of controversies on minor points, we may say that such coal as we have in Michigan is universally believed to have been formed from the deposits of decaying vegetation. Wood and peat have been turned into coal, both by accident and by intentional experiments. That the coal of our coal measures was thus formed is shown, not only by the stems and leaves that are often preserved in connection, especially in the shales above and below, but by a woody texture which may often be brought out even in comparatively massive and uniform beds of coal, by sections of it cut so thin as to be translucent like veneers. For the nature of the vegetation one must consult more extensive works, like Lesquereux's Coal Flora, published by the Pennsylvania State Geological Survey (p. 635). All the specimens sent to Lesquereux by Rominger were the floating stems known as *Stigmaria (ficoides) verrucosa.* Fragments of forms known as *Calamites, Lepidodendron,* and *Sigillaria,* which are plants allied to the scour-rushes, club mosses and ground pine. Ferns are comparatively rare. Rominger who was a careful observer reported them only for Sixmile Creek, north of Owosso. Recent openings have, however, given us a better chance, and they are now known from Grand Ledge, the Standard Mine, Saginaw, and other points.*

Recent investigations have shown that the spores of such plants (like lycopodium powder or pollen) have helped to form quite a part of the coal, especially cannel coal. Seaweed and the herbs and

---

*Page 44.

plants of dry climates, like the cactus, do not furnish much coal-forming woody fibre.[*]

When we come to ask how much vegetable matter is required to produce coal, having due regard to the facts that coal is about twice as heavy as wood, and that wood contains much beside carbon, and that some part even of the carbon escapes in the process of conversion to coal, we find the shrinkage estimated at anywhere from 1÷10 to 1÷30.[†]

We can obtain some idea of the compression by noting how thin stems have become, which are turned to solid bright coal. The breadth will be somewhere between the diameter and half the circumference of the original stem. In a stem turned to solid coal which I recently noticed, the thickness was 1÷16 of an inch, while the breadth was 1¾ inches, indicating a compression of 1÷18 to 1÷28.

Thus to account for a bed of coal five feet thick we must account for the formation of a bed of vegetable matter over 60 feet thick, intermixed with considerably less than 10 per cent of sediment. This is not an extraordinary requirement, for peat bogs have been found 200 feet thick, with no bottom even then, and even in Michigan I have reports of a case where a fifteen-foot pole has failed to find the bottom of the soft semi-fluid muck under the comparatively firm top of such a bog.

§ 2. Kuntze's classification of theories of coal formation.

Dr. Otto Kuntze in a recent work,[‡] has given the most exhaustive and recent schedule of the ways in which the deposits of vegetable matter for the formation of coal may be formed. I translate his summary freely. His terminology is rather cumbersome. I do not recommend it.

I. Local or indigenous (Autochthonous) deposits: in which the deposition of the coal forming substance took place directly on the ground upon which the vegetation grew, without the intervention of water to spread it out in layers; with, interlaminated

---

[*] Otto Kuntze Geogenetische Beitraege, Leipzig, 1895, 1895, p. 63.

[†] Englehardt, cited in Kuntze's Geogenetische Beitraege, p. 65, gives 30÷788; Keyes Iowa, 1892, p. 48, says that 4.5 feet of coal are equivalent to 30 ft. of wood, or 4 ft. coal= 60 ft. peat; Bain, Journal of Geology, Vol. III, p. 648, supposes a contraction of 1÷10 or 1÷16; Lesquereux (Pennsylvania Report P, p. 610) says that the annual layers of peat are about 1 inch thick near the surface, at 10 to 12 feet below are compressed and consolidated so as to be but 1÷10 of an inch, while in coal they are but 1÷20 of an inch thick, according to which it would take 240 years, or, if the coal plants grew twice as fast as peat, 120 years to form a foot of coal.

Sollas, Science N. S. Vol. XII, p. 308, following A. Geikie, estimates that peat bogs may have grown 6 feet per century, and coal 1 foot per century.

[‡] Geogenetische Beitraege.

layers or rather streaks of sedimentary coal formed from leaves as an unimportant exception.

Under this head we have the following subdivisions:

1a. Subtropical or tropical layers of lignite, i. e., brown coal, formed from forest clad swamps, without Sphagnum.

1b. Recent peat formations, in cooler regions, formed by Sphagnum, i. e., floating swamp mosses.

1c. Mixed formations, from swamps only partly overgrown with trees and shrubs (like our tamarack swamps or the southern cypress swamps), which are from time to time flooded with irregular deposits of sediment which produce lenticular laminæ that run out in all directions; this is because the growth of vegetation was continuous, and the repeated floods irregular and local, the detritus being generally drifted in different spots each time.

1d. Littoral swamps with irregular marine or brackish water admixtures, which may be explained by local alterations of the delta (formation of bars and tidal action) without catastrophic marine inundations.

1e. Leaf coal, formed by the falling leaves and twigs of trees that grow on the banks of stagnant waters, which sink on the spot, are carbonized by the humic acids, and somewhat assorted and leveled off by the water. To this method of formation Kuntze attributes only coal streaks,—so subordinate components of the country rock or the coal (like the present formations in forest clad marshes) that they may merely smut, as it were, the principal mass of the coal or the country rock.

II. Derived or Transported (Allochthonous) deposits: those deposited irregularly in coarse fragments at a distance from the point where the vegetation grew. Only powdery detritus is deposited in laminæ if it floated away.

2a. Driftwood or other wood buried by accident (from trees or forests overturned or sunken with the soil) may form almost negligibly small components of the rocks or mere streaks of coal, but not layers of coal.

2b. Displaced coal beds, transported for example by ice action. The fragments of coal often found in the gravel and till, would be classed under this head. They are especially common in Michigan, in the sands and gravels, and especially when struck in wells often excite hopes which can only be disappointed. No coal without a good roof, and no coal that occurs in the surface clays, till, sand, or gravels, has any commercial value.

2c. Sedimentary peat: The very finest peat detritus is in exceptional cases somewhat washed away and may help to form,—

c′. Lake peat, with few or even no clay lamellæ, which are often visible only with a miscoscope.

c″. "Papier torf," i. e., bituminous clay with infusorial earth charged with silicious diatoms.

c‴ "Blaetter kohle," foliated coal, i. e., a marly clay with a little sedimentary peat mixed.

III. Marine (Pelagochthonous) deposits: Coarse waterlogged vegetable matter is deposited directly beneath the vegetation (which grows on the surface of the water) in sedimentary layers; a by-product is the powdery detritus which is often washed out of the coal-forming substance and deposited apart by itself as anthracite. (This theory of Kuntze as to the nature of anthracite is not generally accepted.)

3a. The normal Carboniferous coal beds (paralische) are, Kuntze thinks, composed of the remains of floating forests, which grew out on the open sea. Such beds, he says, show no remains of trees that root in the mud, except in narrow districts that are near the margin, but are composed only of sedimentary laminated coal extending often over vast stretches, and in hundreds of beds which alternate with strata of inorganic material, each bed remaining nearly constant in thickness or running out in one direction. To this group he assigns the "paralische" coal fields of Naumann, which are most finely developed in North America and China, in which the many thin coal beds alternate with much more heavy strata of sediment and are not infrequently replaced with marine limestone. There are, however, also very thick as well as widespread pelagic coal fields. This is Kuntze's pet theory as to origin of coal, for which he argues at such length that reference must be made to the original article.

3b. Coal beds formed in the arms of the sea; more limited but in part very thick layers of laminated coal. Frequently on the side toward the deep ocean the coal layers wedge out into many separate layers, interdigitating with marine beds. Beside the remains of the floating marine forests are also abundant remains of trees that root in the mud. This group is most beautifully developed in France.

Here belong in part the marginal ("limnische") coal basins of Naumann, who did not yet at that time divide the black coals into Tertiary coals without and Carboniferous coals with minute lamination. The Carboniferous coals are characterized as themselves marine formations by their frequent transition into marine limestone, and this also applies to the marine basin formations. The expression limnic, Kuntze would retain only for continental basins.

3c. Amorphous anthracite; consisting of the very finest detritus, with microscopic layers of clay, washed away and deposited by itself, from the Silurian to the Upper Carboniferous, in all regions, generally forming irregular layers. By anthracite in this sense is understood only the kinds most rich in carbon, which show no microscopic lamination, and "faser" or splint coal, stone coal, "staub" or small coal, and coking anthracite are excluded. Such amorphous and yet sedimentary anthracite, which, however, generally encloses "faser kohle," are, he thinks, only washed out of some other magma. Whether there are silurian anthracites which have been formed out of herbaceous vegetation only, Kuntze leaves an open question.

Really, however, to the cannel coals and certain laminæ in every bituminous coal this method of formation could better be assigned than to anthracite, which differs from bituminous coal in secondary alteration more than in anything else.

Of the various methods 1b and d and 3b and c seem most important in considering the origin of our Michigan coals.

§ 3. Theories of Lesquereux and others.

Lesquereux was by far the ablest upholder of the theory that the coal was formed practically like the peat of bogs, and the Annual Report of the Pennsylvania Geological Survey in 1885* gives the latest account of his views, and at the same time of Kuntze's theory (3a), which he considers of all others the most able rival to his own. But one of the objections which he urges to Kuntze's theory, the conformability of the coal to the underlying beds if we may believe Winslow,† will not hold. The presence of underlying fire-clay beds, which is another argument which he uses against Kuntze's theory, is not universally true, and even when true would not, as it seems to me, exclude Kuntze's theory. One of the chief objections to Kuntze's theory in my mind is that so frequently heavy sandstones and other

---

*Pages 94, 114; see also the final report 1895, pp. 1929-1930.
†Winslow, Mo., 1891, Chap. 1.

beds that appear to be formed along shore occur in the coal formation, that one can hardly think it formed far from shore. Moreover, there is no doubt that the tendency of recent investigation is to limit the extent of the continuous coal beds, in the Mississippi region at least, far more than either Kuntze or Lesquereux realized.* But as Lesquereux lays great stress upon the capacity of bogs to form floating superficial mats of vegetation, and speaks of the coal plants "Borne upon a solidly compact raft of creeping Stigmaria," and since he and Kuntze both agree in regarding the Stigmaria, contrary to a current view,† as horizontal stems, like those of the ground pine, but in water and with water leaves, serving to float (freely like the bladderwort, Utricularia), various kinds of vertical stems, their theories are really not so far apart. Both Kuntze and Lesquereux agree in what is a matter of common observation, that very little matter is carried away by rivers out of swamps, and with that the observation of every one will agree.

The wisest policy is to consider all possible methods of formation until the circumstances of each coal seam indicate the one or the other origin for it.

§ 4. Practical bearing of different theories.

And yet as we find one method of formation more and more indicated we shall look to it more and more as the method of formation in cases when it is important for us to know in advance how a seam was formed. For these matters, interesting as they are as pure speculation, and fascinating as it may be to reconstruct the coal depositing forests in our fancy, have also a practical importance.

For instance, the 147-foot coal of St. Charles is much farther above the Marshall sandstone than the 80 to 120-foot coal at Sebewaing. If Kuntze's theory is applicable to the Sebewaing coal bed, we are likely to find it everywhere at nearly a uniform distance above the Marshall sandstone. If, on the other hand, the Sebewaing coal was formed merely as a marginal bog, we need not expect to find it in strata which formed at the same time near the center of the basin. Or if it does extend out that far it may be above coal seams which were formed earlier at a time when the coal basin had not settled so far. A coal seam twenty feet above the base of the coal formation at the center of the basin would be earlier formed and geologically older than one an equal distance above the base of the formation

---

*See below, pp. 31 to 41, also the Indiana report.
†Report P. p. 602.

at the margin. If Kuntze's theory applies we may expect to find the Sebewaing coal, which is about 142 feet above the Marshall sandstone, far below the St. Charles 147-foot coal, which must be over 500 feet above the Marshall.

Chemically, however, the Sebewaing and other coals of the margin are more like the upper seams of the center. The Sebewaing resembles the Lower Verne coal which can almost continuously be traced to the seam at 100 to 150* feet around St. Charles, while the deep seam at St. Charles, between 180 and 200 feet down is chemically like the Saginaw coal, and drilling indicates that it is nearly continuous. There are still lower coal horizons than this, so that if Kuntze's theory is applicable here, a correlation of the Sebewaing and Jackson seams with those of the Verne mine and the shallow seams of Bay City would be entirely inadmissible. In the one case we should expect to find the Sebewaing coal below the St. Charles upper coal; in the other we should not.

Keyes supposes the Iowa coal to have been formed in part, and mainly in marine swamps, but in part also in fresh water lakes, and in estuaries where driftwood might accumulate. Orton† ascribes a marine origin to many of the lower coals, and feels confident that the Sharon coal, to which, as we shall see, some of our coals are probably equivalent, was formed on the spot, in marginal swamps with the sea nearby, while the Freeport coals he takes to be fresh water coals.

David White assumes that the conditions of formation of the Pottsville formation in Pennsylvania were "a continuous broad base-level, coastal-plain shore and currents both strong and varying, so uniform and so rapid as compared with the geologic time required for the sedimentation of the terraces that the similar associations of identical species occurring at different points along the coast are to be regarded as approximately contemporaneous."† "Brief periods of stability or even slight reactive uplifts, in conjunction with bar-forming currents may have assisted in producing lagoons, coastal swamps or other conditions suited either to the accumulation of vegetable matter or to the deposition of thin beds of argillaceous matter." Thus we see that geologists of adjacent States are not inclined to ascribe to all their coals exactly the same conditions of formation.

---

*See Pl. IX.
†Pages 812, 822.

§ 5. Probable formation of Michigan coal.

But on the whole the conception of the way our Michigan coal formed which it seems to me best satisfies the conditions of its occurrence is somewhat as follows: The center of Lower Michigan was occupied by an arm of the sea, or more likely an independent sea, like the Black Sea, opening to the southwest. The land had been higher (during later Kaskaskia time and while the Parma sandstone was depositing) just previous to the formation of the Coal Measures, and was settling slightly so that the river valleys were flooded like the shore of Western Michigan and Monroe county at the present day. The inlets, which are characteristic of a settling shore and represent the flooded lower parts of river valleys are often cut off by sand bars and dunes from the main sheet of water. Such are the lakes upon which Benton Harbor, Grand Haven, Muskegon, and Manistee are built. Out from the margin in the bays and inlets may have crept great floating bogs or mats of vegetation, tropical, closely matted, slowly decaying and weighed down by the ever-increasing growth above. Occasionally it became overburdened and sank bodily,—an accident which happens nowadays to floating peat bogs overgrown with forest,—or the water logged part dropped bit by bit to the bottom. This green carpet over the water kept pushing farther and farther out and was somewhat like the ice forming around the edge of a lake in winter. Like that, too, an occasional storm would drive it back in winrows and perhaps swamp it. This floating forest shed abundant spores and pollen-like powder, which were blown and drifted all over the sea, helping to make a carbonaceous mud, which later became black shale, cannel coal, or bituminous limestone.

The rivers contributed their share toward filling up the sound, which may have been shallow, like Saginaw Bay, where the rushes wave from the water thousands of yards from the shore. There were probably minor oscillations between sea and shore, but on the whole for a while the land sank relatively and the sea overlapped unconformably on the land. Then the sea level remained fairly constant until the sea was largely filled up. Then the land rose and erosion began. But that we will consider later. I beg the reader now to hold this conception culled from the various theories in his mind, and as we pass to consider the actual facts as to the way in which Michigan coal occurs, to compare it with them, for it is by the facts that it and every other theory must be judged.

There are one or two of Kuntze's arguments, however, directly applicable to our Michigan basin, which we shall not have occasion to bring in later, and may glance at now.

In the first place, we may naturally account for the salty water which saturates the formation by supposing that the rocks were originally laid down in water at least brackish. In the same way the sulphates which are characteristic of the waters of the coal series may be derived from the sulphate of lime in the sea water, either directly or through sulphides which were themselves derived from the decomposition of $Ca\ SO_4$ by organic matter, the S, or rather H_2S, set free picking up iron from bog iron ore.

If this is the origin of the sulphide of iron which is so constantly associated with the coal we can understand why there is practically no excess of sulphur, but just enough to combine with all the iron. That is what the chemist would expect if the iron and organic matter precipitated the sulphur from an excess of sulphated waters.

It is, however, conceivable that the salt and sulphates were derived by percolation from beds below, or by erosion of these beds, around the margin of the sea.

We may also note that our former State Geologist Dr. Rominger agrees with Kuntze in thinking that the Stigmaria were creeping stems (rhizomes). "Some of them," says Rominger,* "are found covered with leaves radiating in all directions—as if the apex of a branch had been immersed in the liquid clay paste without any disturbance of the expanded leaves. The leaves are long and bandlike, flat at the outer end, sub-cylindrical, clavate and connected at the basal ends with the stems."

---

*Vol. III, Part I, p. 127. See also Scott's Studies in Fossil Botany, reviewed in Science, March 8, 1901. He considers them rhizophores.

CHAPTER III.

OCCURRENCE OF COAL.

§ 1. Structure of coal.

If we examine a piece of our Michigan coal we see that it has a very distinct cleavage in one direction, though the cleavage is along warped or irregular surfaces, upon which frequently appear fragments of vegetation, apparently bits of rushes turned to coal. This cleavage runs parallel to the bedding and in the mine lies usually nearly horizontal. At right angles to this cleavage, standing nearly vertical in the mine, the coal is also divided by partings, known as joint planes or the cleat of the coal. The better developed set is generally called the face of the coal and the other the butt, and when they are both well marked and at right angles or nearly so, as is often the case, the coal is cut up by them into blocks or rough cubes, and is called "cubical coal," or "block coal." Where they are well developed it is easier to get the coal out in large masses, and in laying out a mine the endeavor is so to lay it out that the working faces will run parallel to the face of the coal. A charge of powder will then blow down the largest amount of coal from the under cut face instead of wedge-shaped pieces, as it would if the cleat of the coal ran diagonal to the working front. When the face parting is much the better developed the term cleat is sometimes applied to this alone, but sometimes the difference in the two partings is very slight, and their naming a matter of custom and convenience, and sometimes the cleat is very poorly developed.

These partings cannot be put through anywhere in the coal, but occur at certain intervals. They are often smoother than the bedding planes, and not infrequently spangled with bright brassy coatings of sulphide of iron. This is a deleterious ingredient, but the spangles on these planes make a great deal more show than they do harm, and do not introduce half the amount of sulphur that is introduced in little obscure, hardly observable, apparently insignificant streaks parallel to the bedding. The sulphur is, as Mr. Hilton has shown (pp. 59 and 99), almost entirely in the shape of sulphide of iron, but the water of the region is strong of sulphate of lime, in which form the sulphur is by no means so injurious. I have seen little crystals of sulphate of lime (gypsum) on the faces of the coal. The analyses of Table A, Chapter VI seem to show that the sulphur naturally present as sulphates is less than one-third of one per cent.

Sometimes, too, the cleat faces are covered with thin white coatings of carbonate of lime, "spar" or fibrous gypsum.

If we look at these joint planes carefully we shall find on their surface the direction of cleavage or bedding marked by a series of lines where it cuts across thin laminæ. Some of these laminæ are bright and pitchy in lustre (German "glanz-kohl"), and are an essential constituent of cubical or block coals. Other laminæ are dull in lustre, soft black, have more the structure of charcoal, and have indeed the woody structure better preserved. These laminæ are known as fossil charcoal, mineral charcoal, fibrous coal (German "faserkohle;" in Great Britain "mother of coal"). Occasionally we may see dull, slightly brassy heavy streaks of sulphide of iron. Even when it is so smeared and sooted with intermixed coal as to appear black, such sulphide of iron may still be detected by the extra weight, and is sometimes known as black jack. But there is another black jack which is a sulphide of zinc, that I have seen in nodules in shales above the coal. Black jack is a term also occasionally applied to black slate, "jack" implying in a general way something of which to be rid. The iron sulphide is so much heavier than the coal that the coal may easily be washed free from a good deal of it.* A coal with much sulphur will, if left in a damp place, soon begin to split and become covered with delicate white needles which have a nasty inky taste, being made of vitriol (sulphate of iron, melanterite).

If our Michigan coal is put on top of a hot stove, it will yield after the steam is first driven off an aromatic smoke, long before it catches fire. This may be burnt as a gas. The matter thus driven off is the volatile combustible, a so called bituminous matter (it is not really chemically bitumen), which is present in all coking and

---

*See article in the Trans. Am. Soc. of Mech. Eng. Vol. XVIII, No. 708, Dec. 1896, on "The Washing of Bituminous coal by the Luhrig process," by J. V. Schaefer, Chicago, Ill. The Campbell washer is also much used.

gas coals. Michigan coal is to be classed as a bituminous cubical or block coal, inclining to be a gas coal and a coking coal, though these latter two qualities differ in different seams.

As all the coal of Michigan is probably not of the same quality it may be well to describe the different kinds of coal.

§ 2. Varieties of coal.

We arrange the varieties of coal, so as to treat first those which have the most carbon in a fixed* condition, i. e., in such a state as to be burned off only at a red heat or higher, and not so combined as to be evaporated away in the aromatic smoke at gentler heats.

Graphite, the last stage of alteration of vegetable matter, is pure carbon except for the mineral matter. An impure graphite is found and mined in the Upper Peninsula of Michigan near L'Anse and is a frequent constituent of the Upper Huronian Slates.

Anthracite, hard, "stone coal," with but 3 to 10 per cent of volatile matter, as the analyses below given indicate. Almost all the anthracite used in the State comes from the Lehigh Valley in Pennsylvania, and in spite of newspaper reports, none has been nor is likely to be found in Michigan, at any rate in commercial quantities. Some of the so called graphite of L'Anse and the associated black slates is anthracitic in nature.

COMPARATIVE ANALYSES OF DIFFERENT KINDS OF COAL.

	Fixed carbon.	Volatile carbon.	Water.	Sulphur.	Ash.
Anthracite, Lehigh, av. of 20 analyses.	:89.25	: 9.86	:	:	: 4.20
Anthracite, Schuylkill, av............	:89.083	: 2.494	: 1.457	: 0.252	: 6.701
Semi-anthracite, Lykens Valley, Wisconasic, av. of 30 analyses......	:83.30	:10.42	:	:	: 6.11
Semi-bituminous, Tioga Co...........	:67.791	:20.505	: 1.65	: 1.257	: 8.852
Bituminous, Massillon, Ohio..........	:61.40	:32.90	: 4.10	: 1.07	: 1.60
Bituminous, Massillon, Ohio..........	:53.5	:37.00	: 5.5	: 1.1	: 4.00
Bituminous, Connelsville, Pa., coking.	:59.61	:20.107	: 1.26	: 0.784	: 8.33
Bituminous, Butler Co., Pa...........	:48.967	:39.883	: 1.91	: 1.968	: 7.222
Bituminous gas coals, Clarksburg, W. Va......	:41.60	:56.74	:	:	: 1.00
Peytons, cannel, W. Va..............	:41.00	:46.00	:	:	:13.00
Clarksburg, cannel...................	:45.43	:49.21	:	:	: 5.36
Coshocton Co. Ohio, cannel..........	:44.50	:44.40	: 1.50	: 1.72	: 9.60
Lignite, Golden, Col..................	:47.58	:34.75	:13.67	:	: 4.00

Semi-anthracite and *semi-bituminous* coal, has 10 per cent to 18 per cent volatile matter; is laminated, with bituminous layers and thin partings of cannel coal, or mineral charcoal; makes a dense coke especially good for blacksmith's work; has not yet been found in Michigan and is not likely to be except in subordinate quantity.

---

*See Chapter IV, p. 63.

The Pocahontas coal stands on the line between semi-bituminous and bituminous. See also analyses in Chapter IV.

Bituminous coal, with over 18 per cent volatile matter, of which about 4½ is hydrogen combined with carbon. This is the family of coal to which Michigan coals belong, and is subdivided into:

Steam coal (block, or cubical, when it breaks readily into rectangular pieces, *splint, furnace,* or *soft coal).* Open burning, with thin layers of cannel coal or mineral charcoal alternating with pitchy lustrous layers, melting and sometimes caking, but not compacting into coke. It may contain less bituminous matter than coking coal, but not always, and the line between these coals and coking coals is rather vague, and the connection with the composition of the coking property, not clearly made out. In fact, organic substances of exactly the same ultimate composition will, on being burnt, the one coke, and the other not, and a coal which will coke when first taken from the mine, may cease to do so when exposed to the air for a few days. Sometimes pulverization aids coking. Exposure to air deteriorates bituminous coal.[*]

Coking (cementing, or *caking)* coal, is quite high in bituminous matter. The pitchy layers are broad, and separate thin dull laminæ which are often broken. They are low in water, and may have from one-half per cent to 15 per cent ash. For the coke to be of most value it should be clear, bright, hard, open textured, with little sulphur. The best and simplest test of the coking capacity of a coal is to try it.[†]

Gas coal is usually a coking coal, but may be a cannel coal. It should be high in volatile matter and free from sulphur. All Michigan coal seems to run high in volatile matter.

Cannel coal is a very bituminous coal with a considerable amount of ash. One essential feature is the structure which is more compact than that of ordinary coal, so that it has not the alternation of light and dark laminæ. Usually it is less pitchy and brilliant, though some varieties (jet) will take a high polish, but it is always uniform, and is a good gas coal. It is also a favorite coal for household use, as the large amount of ash, acting as a wick, makes it burn

---

[*] Orton, Ohio, 1893, p. 268; also Hale, R. S. and Williams, H. J. Am. Soc. of Mech. Engineers, Vol. XX (Dec. 1898), No. 798.

[†] Sulphur seems rather to aid coking, but cannot be over 1% in coke for iron furnaces and anyway is not a desirable ingredient. Generally it can be largely driven off in coking. Moisture does not aid coking. Some coals will coke when ground fine,—disintegrated, which will not do so when heated in coarse lumps. There is an important article on by-product coke ovens in Mineral Industry for 1895.

with less smoke. Hence its name cannel, i. e., candle. It "represents the carbonaceous mud from the surrounding swamps which furnished the cubical coal," and passes into black shale. In its make-up lycopod spores and pollen-like matter play a large part. The Michigan coals seem to lean generally toward cannel coal. It is often difficult to know where to draw the line, as I have elsewhere remarked* between cannel coal and black shale on the one hand, and common bituminous coal on the other.

Black shale while it does not show the layering of ordinary bituminous coal has a very well marked cleavage parallel to the bedding. The relatively weak development of any structure parallel to the bedding so that the coal is quite likely to break with a shelly conchoidal fracture in any direction, is one of the main physical characters of cannel coal. If we draw the line by this physical test, however, we shall include under cannel coal, a good deal of what is often called bone coal, which has very inferior fuel value, yet is really a low grade cannel coal. Practically the line is sometimes drawn arbitrarily at 20 per cent of ash, and any coal which has over 20 per cent of ash is not counted as a cannel.

To one who is unfamiliar with coals, the following tests may be of help. If the substance shows bright and dull bands and in burning, that which is left after it ceases to burn with a yellow flame, appears black and melted, and full of bubbles (at any rate under a lens) it may safely be set down as bituminous coal. If the heat is continued the glow lasts quite a while when removed from the fire, and it slowly burns away, losing most of its weight, to a white or red ash.

If the substance does not show well marked bands, frequently breaks with a smooth, shelly fracture, and if on heating, after it ceases to burn with a luminous flame the ash is white or red or soon becomes so, and retains the original shape of the fragment, and appears to be a considerable proportion,—over one-fifth of the original, it may be classed as black shale, if it splits readily parallel to the bedding, or as bone cannel coal if it does not. If on the other hand there is no fissility parallel to the bedding and the amount of white or red ash left after complete combustion is less than one-fifth of the original substances we may safely call it cannel coal.

Above the coal seams there are frequently a few inches which

---

*"On the border line of coal," Michigan Miner, Vol. II, No. 1, Dec. 1899, p. 17.

vary in character from bone cannel to black shale, and contain shells shaped like a tiny flat spoon of *Lingula mytiloides*.

Some of the material tested by Mr. Willcox (Chap. V, pp. 78-80) is of this bone cannel.

Beside the black shales associated with the coal there are others among Michigan rocks which have led to much waste of money. Most conspicuous are the Devonian black shales, which run across in a band from the south side of Thunder Bay to Charlevoix and Antrim counties, and from Port Huron and Detroit southwest. An analysis of one such shale, from south of Alpena, showing its fuel value is given in Part I of this volume on p. 47.

It will be noticed that the analyses of Michigan coals given in Chapter IV, most resemble among the analyses of other coals given for comparison, those of cannel and gas coals. This is especially true of the Verne coal seams. The very large amount of volatile matter which seems to be present makes an excellent gas coal, whenever a coal low in sulphur can be obtained. The Saginaw coal is very low in sulphur, and tests given below indicate that it would give a good fuel gas.

Comparing the three deleterious constituents, ash, sulphides, and volatile matter, and arranging the uses according as they can stand or prefer more or less of them, we get the following table:

Volatile matter	: Ash	: Sulphur
can stand much of the ingredient		
: gas man'f	: gas man'f	: steam making
: coking	: domestic	: domestic
: steam making	: coking	: coking
: smith work	: smith work	: smith work
: domestic	: steam making	: gas man'f
Presence of the ingredient disadvantageous.		

Both the Sebewaing, the Wenona, the Jackson coal and in fact the Verne seams generally are coking coals, and when they are used as steam coal tend to run together, and mass on the grate unless properly handled with a special grate. In spite of the coking properties, the percentage of sulphur in the Verne coals is often too high to make good gas coal or coke without wasting. Water is also high. The sulphur combined with iron is more harmful in other ways than in heat production. Coals with iron usually give red ash. The Lykens anthracite coals are known as red ash coals and our Michigan coals are geological equivalents. A white ash coal is probably pretty free from sulphur as well as iron. If in the analyses of the Sebewaing coal, we assume that there was originally enough iron which has all gone into the ash as $Fe_2 O_3$, to make $Fe S_2$ of all the S, almost all of the ash must have been iron oxide and all the coal combustible except the water. The amount of heat given out by the Sebewaing coal is very considerable.*

Lignite or *brown coal* is a form intermediate between peat and coal, which is not found practically important in Michigan, though an important fuel in the far west (see analysis of Golden coal), and if present would not be likely to be used in the presence of abundance of coal. The same remark applies more or less to—

Peat, which is the consolidated mass of vegetable matter, largely moss, which is found in and beneath peat bogs, and is often called muck, but contains more mossy and woody substance than the proper muck, being composed largely of sphagnum mosses.

The cranberry marshes and tamarack swamps are the localities where peat most abounds, and up to the present peat has been known in Michigan chiefly as the base of the famous celery and peppermint soils, though for such culture, there must be about one-third of minerals constituents and sand; i. e., ash. In other words they are truly muck. Moreover they must not be acid. Peat frequently is. Analyses of these soils are given in Bull. 99 (July, 1893), of the Agricultural College. Peat has also been used, more especially the mosses which produce peat, as a packing for nursery stock.† Winchell‡ also has given quite an account of the various uses of peat.

Peat is the characteristic fuel of Ireland and has been used in other places for a long time, but its exploitation as a fuel has made great advances of late owing to the introduction of improved machinery in cutting and preparing it.§ It is also said to be available for the production of fuel gas, ammonia sulphate, acetate of lime, methyl alcohol, tar and coke briquettes,—that is to say, the same products which are given by the distillation of wood and soft coal.

There are a number of peat factories in Ontario, where there is no local supply of coal. It is said to sell for about $3.75 per ton.

An unsuccessful attempt reported in Vol. I, Part I, p. 56, of these

---

*Chapter IV, Analysis A9.

†Sherzer, Monroe County, Vol. VII, Part I.

‡1860, pp. 192, 193.

§See "Die Torf Industrie * * * " by Dr. Theodor Koller, published in Vienna. Hertleben, publisher, 1898.

reports was made to use it for fuel in pig iron manufacture. But beside the amount of water contained which runs from 10% up, it is liable to run rather high in phosphorus.

Peat bogs are very abundant in the northern part of the state* as well as in the southern and often occur in connection with, and sealing over marl deposits, and possibly they might be used in cement manufacture. Many descriptions will be found scattered through the reports of this survey from the time of Douglass Houghton on. Near Chelsea on the Michigan Central railroad are extensive deposits of peat, and the Chelsea Compresso Peat Co. has been organized to exploit them.†

The following analyses from Fritsche may be compared with Tables B and K of Chapter IV. Peat in the bog, it must be remembered, is very wet and entirely unfit for fuel, and the amount of drying and consequent loss of water in the merchantable product varies greatly. A peat with 16% water and 8.5 ash will yield about 3,800 to 3,900 calories. See p. 118.

	H20	C.	H.	O.	N.	Ash.
Harz, Germany..........	10-90%	50.86	5.80	42.57	0.77	0.57
Holland..................		59.27	5.41	35.32	1.79	2.04

ASH ANALYSIS.

	K_2O	NaO	CaO	M_9O	Al_2O_3	FE_2O_3	P_2O_5	SO_4	Cl	SiO_2Sol	Insoluble. (Sand.)
Harz................	1.33	1.45	23.78	15.59	10.69	6.76	5.50	10.06	1.82	4.40	17.32
Holland.............	1.2	1.1	11.7	4.5	2.9	5.3	——	9.7	1.5	9.8	51.5

A few other terms often used by miners may also be defined.

Bone coal is a name applied to cannel high in ash, and to coal and slate inseparably mixed, and may show horizontal stratification. It represents a transition toward black shale, but need not be so compact, nor so uniform, nor necessarily so bituminous as cannel coal. A layer of bone coal overlies the main coal at Sebewaing, and is separated from it by a streak of sulphides.

Charcoal is a term improperly applied sometimes to slate and coal mixed, with stratification more or less twisted, and with FeS_2 more or less intermixed, as well as to the duller less altered streaks in the coal, which we have already described.

§ 3. Slate partings.

The mention of slate in coal naturally leads to the subject of "slate" (or more properly shale) "partings," which may be no wider

---

*E. g., 8 feet thick right in Redjacket; See Calumet News, July 31, 1901.

†Detroit Journal, August 24, 1901.

than a knife blade, but often are an inch or two thick, and though very thin may be persistent for a good way. They may even thicken so that what was mined as one bed of coal becomes several distinct beds. In the Glen Mary mine of East Tennessee, the superintendent informs me that the two seams of coal, separated only by a thin parting on one side of the basin, are three feet apart at the bottom, and on the other side have been followed continuously until they are at least forty feet apart. Similar phenomena occur in Michigan, especially in connection with the upper coals. This implies that the distance between different coal beds is not always the same, but may vary greatly. To such an extent is this true that Stevenson hazards the suggestion that possibly all the lower coal beds of Pennsylvania may be splits off from the one great Mammoth seam. This splitting of coal beds cannot be absolutely proved by comparison of disconnected records, but only by following them continuously in mines or in sections made by streams, but we have such proof in Michigan in the Wenona, and Michigan mines of Bay City and many of the records suggest the possibility of such occurrences.

§ 4. Character of the roof.

The usual beds above the coal are everywhere reported to be black shales, and in reports of explorations, unless great and conscientious care is taken, more or less of this black shale is likely to be counted with the coal. Sometimes this black shale is almost a cannel coal, and this is the case with the fossiliferous bed, the Lingula shale, which overlies the coal in the Bay City and Verne mines. Other varieties of the shale roof will be found described in Part I of this volume on clays and shales. The black shale is an impervious roof, which is important when water is so abundant as it is in Michigan, but is likely to be weak, especially when the rock surface is not far above, and requires a good deal of propping of one kind or another.

At times we find coal directly beneath clay, sand or gravel, or other unconsolidated deposits, when it is practically unworkable. Black shale with a firm sandy shale or sandstone above makes an excellent roof unless it peels off and comes down as "draw slate." A sandstone roof directly above will be found a very wet roof. I know of no mine that claims to be working under a limestone roof, though the roof at the Michigan and Amelith shaft of the Pittsburg is a black bituminous limestone full of shells (Productus, etc., see

p. 42), which are like those found at Verne, and the roof of Tod Kincaid's coal mine near Corunna is said to yield 50 per cent of $CaCO_3$. Probably limestone beds are pretty widely associated with the Verne coals.

It is probable that our coals belong in the Pottsville formation, corresponding to the Sharon, Quakertown, and Mercer coals of Ohio, and the limestone roofs are especially found over the Upper Mercer coal and the coals of the Lower Coal Measures. The weakness of the roof has been the ruin of many mines. Next to the water it is the most serious source of expense.*

The deeper coal seams nearer the center of the basin may be expected to be better as to roof.

As we have said, in Michigan the shale above the coal is almost invariably black. Sometimes blue shales are reported, and it is generally blue a few feet above. In fact so characteristically do our Michigan coals appear to be associated with shales, and so rare are the cases when anything but shale, slate or fire-clay, are reported above or below, that they may be presumed to be generally mere local phenomena.† In the overlying shales are very often nodules and bands of carbonates of iron, lime, etc., kidney ores as they are often called from their shape. A very interesting occurrence is that of the nodules which also contain sulphide of zinc with sulphide of iron, which I found in the shales over the coal in the Owosso Coal Co. mines northeast of Corunna; also at Grand Ledge, at the Standard mine Saginaw, at Sebewaing and at Flushing, and also I am told in the shaft on Sec. 7, of James Township, T. 11 N., R. 4 E. I have also found kaolinite.

As we shall later see, there are a number of reasons for considering one of the coal seams mainly worked in Michigan, as nearly equivalent to the Sharon or Massillon coal of Ohio, and it is interesting to note that White‡ speaks of the roof of the Sharon coal as commonly 40 to 50 feet of shale with nuggets of $Fe\ CO_3$.

§ 5. Character of the foot.

The bed underneath the coal (the foot) is usually reported as fire-clay or shale. Probably no stress can be laid on the difference, except that by fire-clay a white or light color is generally implied. Many drillers report all clayey beds under coal as fire-clay, where other drillers report always shale, and a record of a saline or other well for water might report the whole series as merely alternations

---

*Lawton, 1887, p. 133; 1885, p. 173, et passim.

†The difference between what the drillers call "slate" and shale appears to be that the former is harder and slakes less readily.

‡Bull. U. S. G. S., No. 65, 1890, p. 202.

of black, white and blue shale. Fire-clays are shales which will not melt in the fire and will make good fire-brick. They have a large proportion of fine SiO_2 (which is not surprising when we remember how largely plants like scour rushes occur in the coal), and have but little of fusing compounds, like alkalies, lime, etc. As Ries's tests in Part I of this volume show, genuine fire-clay is absent or rare, but clays suitable for making semi-vitrified or paving brick are common. For low grade fire-brick and paving brick, the demand for which is growing, such clays may often be mined to advantage in connection with thin seams of coal.

§ 6. The Michigan coal basin.

The outlines of the coal basin have been shown in Winchell's various maps of Michigan, in Volumes III and V of these reports, and in Nos. 30 and 31 of the U. S. Geological Survey water supply and irrigation paper. A rough map was also given in the preliminary addition of these papers, and in an article in the Engineering and Mining Journal for June 30, 1900, with contours also indicating in a rough way the system of rock channels.

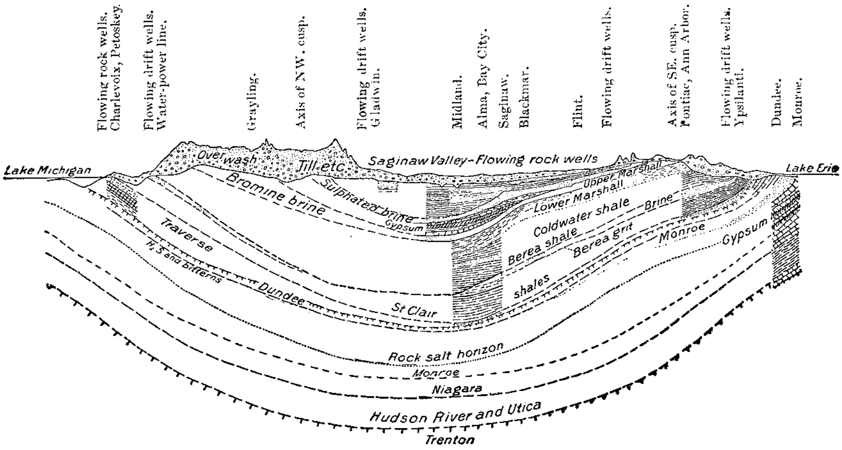


Fig. 1.—Cross section of the Lower Michigan Basin. Horizontal scale, 1 mile=.135 inch; vertical scale, 1,200 feet=.321 inch.

Plate I of this report illustrates our present knowledge. In the Marshall sandstones themselves small streaks and pockets of coal and coaly impressions of vegetation are found also, but have never been found to possess more commercial importance than the driftwood along the beach.

Figure 1 and description taken from my paper on the water supply of Michigan* gives an idea of a cross-section of the strata of the basin from southeast to northwest, only those of the innermost basin above the sulphated brines being the coal measures.

The Devonian black shales are those which lead most often to false reports of coal.

The area enclosed on the map, Plate I, includes also the basal or Parma sandstone, which is, however, not everywhere present. The boundaries of the basin are fairly well known east of the Meridian line, but the northwestern portion is more uncertain. All that we have to go by are certain general considerations as to the thickness and dip of other beds, the relations of the drift and the present topography to the underlying topography, the coal in the drift and the direction in which it came, etc., which are almost too complex to go into here,† and a few scattered drill holes.

Some distance beneath the coal series proper there is a sandstone known as the Napoleon or Upper Marshall, which can be followed in outcrops or in drilled wells from the sandstone bluffs of Huron county into Sanilac and thence southwest past Island Lake and Napoleon into Hillsdale county, and thence northwest, past Battle Creek to Holland, and thence, in wells, on to Grand Haven, Muskegon and Ludington. It is also recognizable in wells around Tawas and northwest, and since it is full of water, which over much of the Saginaw valley will rise to the surface, it has been tapped by a great many wells, for fresh water near the margin, for salt and bromine toward the center. We can thus follow it pretty continuously over two-thirds of the basin.

The greatest depth below surface to which it has been followed is at Midland (1200-1300 feet) and St. Louis and Big Rapids (1300 feet). The outcrop, or what would be the outcrop, were the surface deposits stripped off, is generally under higher land than the surface of the coal basin, which it thus surrounds as a rim. This bed is practically equivalent to the Upper Logan of Ohio. *Beneath it and outside it no coal in commercial quantity has been or is likely to be found.*

This point needs to be emphasized, for in the Detroit papers of

---

*Water Supply and Irrigation paper of the U. S. Geological Survey, No. 30, Fig. 10.

†The cusp dividing the Saginaw and Erie ice lobes we know followed on the southeast the ridge of Marshall sandstone underlying the coal basin. So on the northwest it is a fair presumption that the dividing cusp between the Saginaw ice lobe and that of Lake Michigan, which retired north and northwest from Grand Rapids, followed the heavy sandstones underlying the coal basin,—either the Marshall or the Parma.

Again coal in the till or terminal moraine deposits must have been derived from a source nearer the center of the ice sheet along the direction of lines of motion of the ice. Coal in alluvial deposits must have come down hill.

The coal series appears to have been well represented in the Big Rapids Red Cross well, and coal is found in the drift as far north as Roscommon county. Now coal in the till has always been moved to southwest of the rock outcrop.

March, 1898, I saw a write-up of two columns concerning coal in Wayne county, and not many years ago considerable time and money was wasted in putting down a shaft for coal in Antrim county. More recently some of the pushing business men of Alpena underwent the same experience, and even now, I hear of coal explorations in Sanilac county, at New Baltimore, etc., which are sure to be futile. To explorations for coal outside the limits shown upon the map I can give no encouragement.

It was at one time supposed that the coal fields of Michigan, Ohio and adjacent states were originally continuous and were afterward folded very gently, and the coal on the arches eroded away, while that in the basins being less exposed to such action was preserved. Such was often the case in Pennsylvania. But it is now understood that these fields were never continuous.*

This is of practical importance, for if they had been we might expect to find occasionally outliers outside the main basin. The evidence in the case of Michigan is somewhat as follows: We find overlying the Marshall sandstone, in the deep wells of the Saginaw Valley, a series of shales with beds of gypsum which extend from Alabaster and Huron county to Grand Rapids, where they outcrop.

Now the gypsum (sulphate of lime) is a salt present in seawater, and one of the first to crystallize out, when an arm of the ocean is cut off from the main body and exposed to a climate such that evaporation goes on faster than water is supplied. This gypsum we do not find in Ohio, or other states. Hence it is natural to suppose that the gypsum was laid down in an enclosed basin cut off from the main ocean to the south. As a matter of fact we do find a group of strata, the Logan series,† which occur in Southern Ohio, but not in Northern Ohio where an unconformity indicating that that part of the State was then out of water takes their place. In the same way we find that in Michigan the gypsum series does not extend all over the top of the Napoleon sandstone where we might expect it, but that in some places the beds immediately above—the limestones of Grand Rapids and Bayport—lie directly on top of the Napoleon sandstone. Or as at Corunna, we find the Parma and Marshall sandstones indistinguishable. Again over in Ohio, we find a limestone which must from its fossils be equivalent to these limestones, the Maxville limestone, unconformably overlapping the beds below. Thus we have evidence of a neck of land

---

*Keyes, Iowa, 1894, p. 173.
†Orton, Ohio, 1888, p. 39.

projecting out from the land mass to the north (for Canada seems to have been out of water all this time), through Southeastern Michigan and Northern Ohio, having no deposits of Logan age, and hence a projection of land. We thus have a slight fold indicated, antedating[*] the formation of the coal measures of Ohio and Michigan and lying between them. The only way in which we can conceive the two coal basins to be connected therefore, is by submergence of this axis, and deposition over it. It is not of course necessary to suppose that the submergence extended to the full height of the fold, which was very likely folded as formed. Of complete submergence of this axis there is no sufficient evidence though this low projecting area seems to have been a little higher in the time of the Upper Marshall, i. e., Napoleon, than immediately thereafter. During the time of the Bayport limestone it sank a little, but the character of that limestone and the corals and sand bars and other shallow-water fossils found in it indicates that the depression was not enough to make the ridge entirely disappear.

Almost immediately above this limestone come the coal beds. Over in Ohio fragments of the Maxville are found in the conglomerates immediately above[†] (Herrick) showing that the movement of depression during which the limestone was formed must have been promptly changed into one of uplift which brought it within reach of erosion, so that its fragments could be worn away to be laid down in later formations. So around Jackson this limestone occurs on the tops of hills with the coal beds and coal measure series between and flanking them[‡] in a way that plainly indicates that the coal measures were deposited in troughs in the eroded limestone, so that the margin of the basin at the time of the deposit of these coal measures must have been in the region. It must not be supposed that the smooth outline of the coal basin given in Plate I is exact. It is merely the expression of our ignorance of details. It was probably very irregular and would have been more deeply indented if it had been taken at the top instead of the bottom of the Parma sandstone.

Inasmuch as coal cannot be predicted as certainly present any-

---

[*] A reason for considering that the fold of the Marshall antedates the coal seams is found in the dips. While the top of the Marshall descends from 252 to 700 or 800 feet below the surface from Sebewaing to Bay City and Saginaw, the base of the coal measures descends from 104 or 120 to between 300 and 400 feet only; while it is doubtful if the coal seams descend appreciably.

[†] Geol. Sur. Mich., Vol. VII, Part II (Huron County), p. 293.

[‡] Geol. Sur. Mich., Vol. III, Pt. I, pp. 116 and 129, and private communications of J. Holcroft and F. C. Ward of Jackson; see also Winchell, 1860, p. 117.

where in the coal basin, I have in drawing the limits of it tried to include all the land where it might even *possibly* be present.

As to the limited character of the coal basins in other states of the Mississippi Valley, says Orton of Ohio.* "The subsequent," to the time of the Berea grit, "history of the eastern half of the State depends upon the joint advance of these land masses, the western and northern borders of the gulf. Both seem to have extended themselves in the same manner by a slow and nearly uniform rise of the border," "the lowest coal seam was formed around the margin of the sea;" "the later coals never extended over the outside margins of the earlier swamps." "At the time when the Sharon coal was forming, the area of the gulf in Ohio was not less than 10,000 square miles."

Says Keyes:† "It is a significant fact that the Palæozoic coals of the world are all deposited in more or less limited basin shaped areas."

Winslow‡ gives a map of Missouri, which shows quite well one-half of the basin as it exists there and§ describes the Coal Measures as flanking the Ozark uplift, which took place probably during the Carboniferous.

The following diagram, which is taken from Part II of Vol. VII modified from one issued by Keyes‖ (Fig. 2), shows the general sequence of elevation and depression of the land and consequent advance of the shore to the south or retreat back to the north.

The land rose and the ocean retired south during the Kinderhook (Marshall), and Lower Michigan in part emerged from the water, and continued retiring more slowly during the Augusta while the gypsum series was being deposited in Michigan in the cut off basins. The ocean advanced again during the time of the Saint Louis formation and finally at the time of the Bayport limestone forced open water communication as far as Huron county. Then it retired again during the Kaskaskia so that the Bayport limestone was eroded around the edge,—at Jackson and elsewhere.

The upper Kaskaskia (Chester) and the very lowest coal measures were deposited only in the center of the coal basin, if indeed, that too was not land surface. Then during the time of the coal measures though there was some irregular readvance of the sea it

---

*Ohio, 1884, p. 135; 1893, p. 264.
†Iowa, 1894, p. 91.
‡Mo., 1891, Plate 1.
§Mo., 1892, pp. 109-110.
‖Iowa, Keyes, 1894, p. 114.

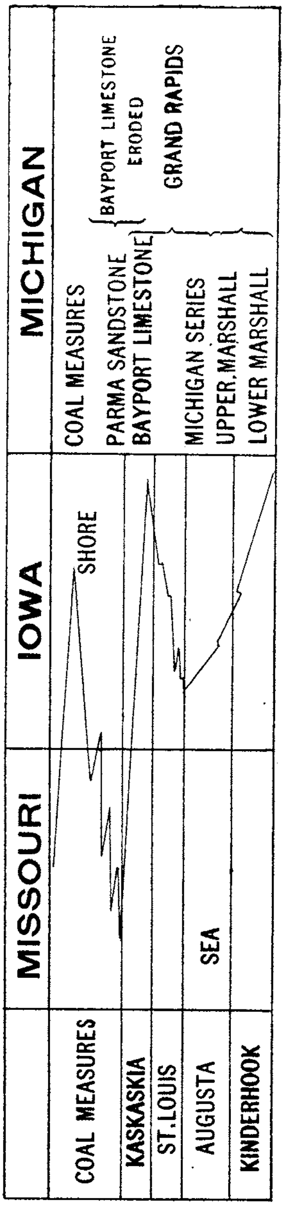


Fig. 2.—After Keyes (Iowa, Vol. II, p. 114) showing how the shore line advances to south and returned north during and before the deposition of the coal measures.

never fairly regained what it had lost, for it filled up nearly as fast as the land sank.

There is another point that shows that the Coal Measures of Michigan were deposited in an arm of the sea, extending into a basin which existed before their formation, and that they have not been folded into basin shape since. Beneath Sebewaing the Upper Marshall, Napoleon, is struck at about 250 feet* and the coal bed is from 85 to 125 feet in depth. At Midland the top of the Napoleon is at 1,200 feet depth, and consequently the coal horizon might be expected at some such depth as 1,050 feet if the strata were parallel. Instead of this at 1,050 feet we are in the gypsum beds of the underlying Michigan series, and we do not find any possible equivalent to the Sebewaing coal until we come to a black shale at 800 feet. The same state of affairs is generally true in the Alma, the Saginaw River wells,† etc. While the Napoleon is often over a thousand feet deep, proper coal measures are not found at over 800 feet depth.

Obviously, therefore, the coal formation is in a broad way more nearly horizontal than the Marshall sandstones and underlying beds, which must have been slightly folded before the coal was laid down. It follows that we cannot estimate the thickness of the

---

*Vol. VII, Part II, p. 145.
†Chapter VII.

coal series from their breadth and the dip of the Marshall. However, the earlier estimates, and in fact the estimates to this day current, concerning the thickness of our Michigan coal measures, being based mainly upon observations near the border, have much underrated them. Keyes for instance speaks of them as not over 200 feet thick, half of which "is occupied by the basal sandstone." Instead of this there is not less than 600 feet of coal measures, excluding the basal Parma sandstone, at Midland, and probably somewhat more farther northwest.

§ 7. Minor undulations in the coal measures.

The coal lies in minor undulations, independent of the general curve of the whole formation and the basin which it forms. These are known to miners as "hills" or "rises," and "valleys" or "swamps." The coal is said to be pockety.

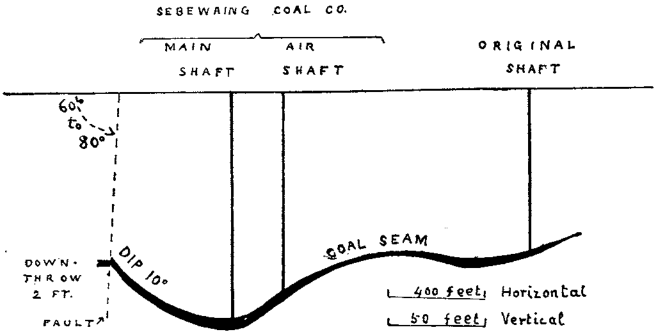


Fig. 3.—Section at Sebewaing Shaft.

Fig. 3, taken from Fig. 11 of Part II of Vol. VII, across the Sebewaing basin shows the structure. It appears again in the diagram of the Woodville shaft, Fig. 4.

I have been informed by the miners at Corunna that the rule is generally true there, and that as Rominger says, "The beds are found in the mine rising and sinking in undulations." At the Somers No. 1 shaft, St. Charles, again the coal is reported to be dipping and thickest to southward. Between Somers No. 2 shaft, and the St. Charles Coal Co.'s shaft are two rises. This is a very important feature in developing coal, for it is obvious that it will be much more economical and convenient to locate the shaft at the lowest points. Then in drifting out, all the water will run toward the shaft, the levels will be kept dry and the water can be lifted by one pump. Moreover the loaded cars will have a down grade, and the empty cars an up grade. A similar structure is described in all other States. Keyes* describes and shows in his figures very plainly the "shallow saucer shaped sheets of coal." Orton† mentions the same structure in the Sharon coal.

These minor undulations seem also to extend down into the Napoleon as we find in following the "lower salt rock" from brine well to brine well down the Saginaw River.

In the Pere Marquette No. 1 mine the coal rose so rapidly to the east that the roof became unsafe and leaky, and the mine is being abandoned and similar undulations might be described from most of the new mines.

In the works of the New Hope Coal Mining Co. near Jackson the trough or valley is barely 150 yards wide, but is several hundred feet long.

In these undulations the coal is generally thicker where lower, and "thins to the rise."

This is the general rule laid down in the text-books.

This is obvious in the workings of the Sebewaing Coal Company, Fig. 3, where the coal is 4½ to 5 feet thick near the shaft, and diminishes to two or three feet at the old first shaft, and beyond that runs out. At the former shaft it is 120 feet deep, and at the latter 86. It is true according to Mr. Holcroft generally in the Jackson region (Fig. 4, p. 33 and Fig. 5, p. 48), and also is known to be true around Corunna.

We find the same law reported for Iowa by Bain‡ and Keyes.§

"The coal may therefore be considered"—"as disposed in numerous basins of more or less area, thickened centrally, but gradually becoming attenuated toward the margins."

Similar facts are mentioned in Ohio by Orton.||

In the lower and thicker parts these troughs of coal are likely to be capped by a smaller coal seam known as a rider.

As the word likely implies, this rule has not been made out with any certainty in Michigan, though we find in the East Saginaw coal mine for instance, above the 3 feet 3 inches of coal at 147 feet a 4-inch rider at 128 feet 7 inches, and another of 1 inch at 104 feet.

---

*Iowa, 1894, pp. 176-179.
†Ohio, 1884, p. 156.
‡Iowa, 1897, p. 299.
§Iowa, 1894, p. 176.
||Ohio, 1884, p. 156.

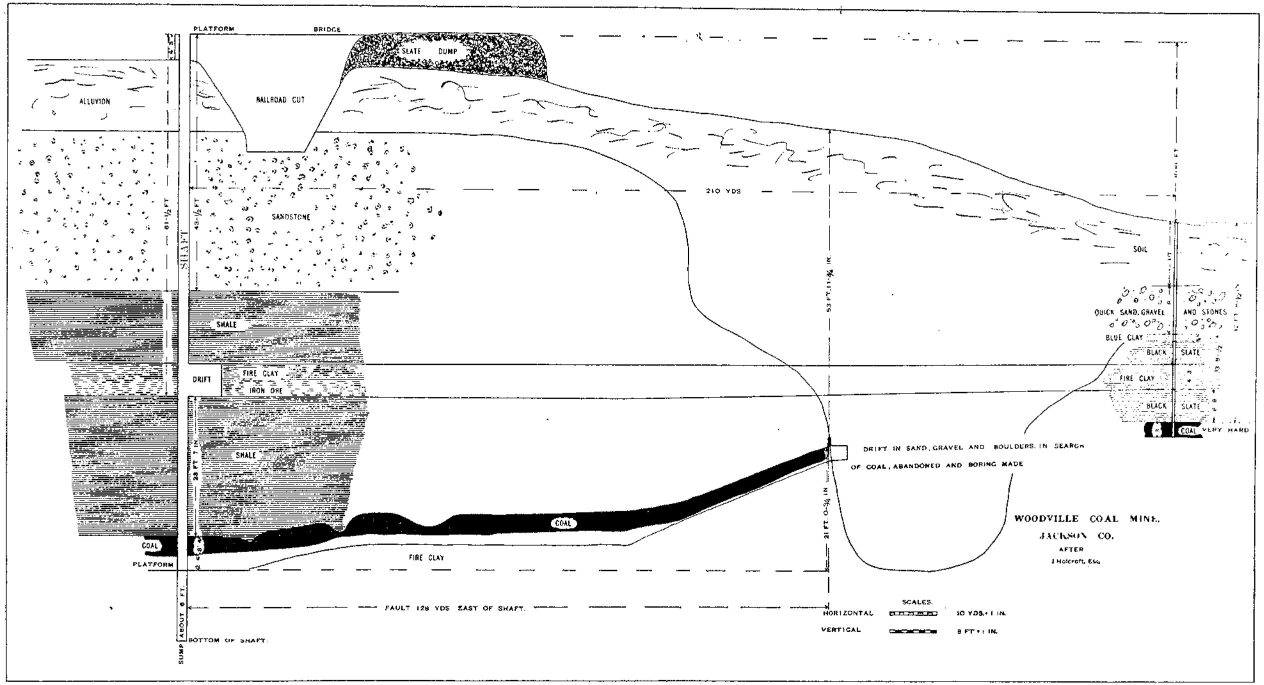


Fig. 4. Section at Woodville Shaft. Illustrating the occurrence of a gravel filled channel or washout, and of undulations and pinches in the coal.

So, too, around Sebewaing, when the main coal is from 85 to 105 feet deep, we sometimes find a little rider at about 71 feet. In naming and correlating the seams I have found it convenient to entitle them thus, in descending order: Upper rider, Upper Verne, Lower Verne, Middle rider, Saginaw, Lower rider, Lower coal. I would not pretend however, that seams which I have thus named are always the same. I know well that my correlations are far from perfect. Nor would I imply that the seams called riders may not at times be thick enough to work. The East Saginaw mines may be on the Middle rider.

This law has been especially developed by Bain,* who gives a theoretical explanation of it, that the shrinkage and contraction of the lower coal bed, which if five feet thick represents about 60 feet originally of peaty matter, in slowly settling and compacting, made a basin in which the upper coal was formed. If his explanation is correct the phenomenon should be widespread, and the presence of riders is also alluded to by Nicolls† as a favorable sign. Thus we may safely say that the presence of small seams of coal is not unfavorable to more coal below.

§ 8. Variation in coal measures.

No one bed of coal extended over all the coal basin.

This is obvious if we regard the coal basin as it now is, for many of the records like those of Alma, St. Louis, St. Johns and Ithaca, which are close to the center of the basin, show no coal. But this might be laid to the subsequent cutting out of the coal, just as the original East Saginaw well‡ struck a big sandstone which replaced all the coal measures down to 171 feet, including the bed at 147 feet which is now worked. But we find a number of the records in the center of the basin lacking coal, and though it is proverbially hard to prove a negative, on close comparison of the records it is hard to see how any one bed could have been represented all over the basin. We find the coal beds at all sorts of altitudes above the Napoleon from 163 feet at Sebewaing to 1,005 feet at Midland. The deep central wells show black shales and bituminous limestones at horizons where coal appears at the sides. As Rominger says on this point,§ "Regularity in the sequence of strata does not exist in the coal formation. The beds in it are usually of local extent,

---

*Iowa, 1897, pp. 299-300; Journal of Geology III, p. 646.
†Story of American Coals, Phila., 1897.
‡Geol. Sur. Mich., Vol. V, Part II, p. 55.
§Geol. Sur. Mich., Vol. III, 1876, Pt. I, p. 128.

so that a position which in one place is occupied by a shale bed may in a neighboring locality be filled by a ledge of sand rock." "The whole series is a constant alternation of shale and sandstone beds, every natural or artificial section teaches us that an immense variety exists in this alternation." Says Keyes,* "Few cases are at present known in which the geographical extent of a workable coal stratum is more than four or five miles."

Also Bain,† "Barren holes are frequently put down in the midst of productive fields, particularly in the Iowa-Missouri region."

We see therefore that we must not be discouraged by the failure of one hole in coal explorations, and on the other hand it requires much more testing to be sure how much coal we really have than it would if the coal were more regular. Bain's detailed sections‡ and our own on Plate IX show well how irregularly the coal is distributed.

In the same way, Orton, speaking of the Ohio coals, says that to expect the earlier formed seams in the center of the basin would be to look for the living among the dead,§ that in no case known does the coal extend beyond 600 to 800 feet below sea level, and "there is no instance known in which the Sharon" (one of the lowest coals) "has been found of mineable thickness directly under a mineable thickness of the Kittaning coals." "A coal seam can often be traced toward the interior of the field along some open valley, or by means of a series of test borings. In numerous instances such seams are found to suffer gradual reduction." Again (p. 135), "The later coals never extended over the outside margins of the earlier swamps. Of Missouri Winslow says,|| "No one coal bed in Missouri can be affirmed to be co-extensive with the area of the coal measures, and within a still smaller area does any one bed possess those characteristics of thickness and quality, or is it accompanied by the other conditions which go to make it workable." The "conditions" which he cites as preventing its workability are inadequate thickness, poor roof, disturbances which have produced faults—and faulty coal, inferior quality, excessive water, excessive depth.

Of these conditions the last, excessive depth, is not likely to occur in Michigan, except that where the coal is deepest the cost of drill-

---

*Iowa, 1894, p. 176.
†Iowa, 1897, p. 292.
‡Loc. cit., Plate VIII.
§Orton, Ohio, 1893, p. 262.
||Winslow, Mo., p. 33; see also pp. 24-25.

ing it up to see how much there is becomes excessively great. But once found in satisfactory quantity and quality the depth will never be a serious obstacle.

Examples of the running out of coal seams in our Michigan properties might be multiplied and it would be invidious to select examples. In one direction they very often pass into black shale, the transition being marked by bone coal or cannel coal.

The coal is more abundant, not far from the margin of the large general coal basin. The coal beds diverge and thin out gradually as they get deeper and lower coals come in. The remaining series thickens toward the center of the basin; in other directions they thin irregularly and suddenly.

Jackson and Sebewaing are on the extreme verge of the coal basin. At Williamston, Saginaw and Corunna, the basal sandstones are not much over 400 feet deep anyway.

Monitor is nearer the center. Wells still nearer the center at Lansing, St. Johns, Midland and Alma, have not shown much coal.

The irregular thickening and thinning in other directions has been touched upon under other heads, and will be referred to again when we come to treat of sandstone channels and bars. It may be noticed in reviewing the records of various explorations that the sudden disappearances of the coal have not been generally in the direction of the deeper part of the basin. In regard to other States in addition to what has been already quoted, Orton remarks:* "All of the coal seams below the Freeport horizon and a number above appear to have been formed as marginal swamps around the border of the sea," and the description of the Jackson county (Ohio) coal mines† that work in the Wellston coal which is "not more than 2½ miles wide and 7 or 8 long;" "on the northern edge of the basin;" rising "growing thinner" "down to a feather edge," "on the southern side" "running into shale and never met farther beyond," shows the mode of occurrence clearly. Winslow‡ gives a figure and frames his hypothesis to explain, "b. How coal beds are more abundant over the marginal area." What White says of the lower coals is quoted below.

As to the question of the parallelism or divergence of coal seams, geologists have held very different opinions. Andrews, in Ohio,

---

*Ohio, 1884, p. 135.
†In Mines and Minerals, Jan., 1899, p. 254.
‡Mo., 1891, pp. 30-31; see also previous pages and p 52.

insisted upon the parallelism of coal beds (coal horizons) and Lesquereux held the same views, and both were experienced workers.

On the other hand, Stevenson and others have brought indisputable proof that coal beds have sometimes diverged from one main mass, and indeed Stevenson has suggested that a whole family of coal seams are but splits from one main seam. Keyes* has made a very plausible attempt at reconciliation in his supposition that the geologists who found a parallelism followed the coal along sections more or less parallel to the shore line of the great arm of the sea in which they were formed, while those who found a divergence studied sections running away from the margin of the basin. Certainly this applies to Stevenson's observations.

Let us see how Keyes' hypothesis will apply in Lower Michigan. The only part of the basin from which we have anywhere nearly enough data to test the matter is the southeast part between Sebewaing and Jackson.

In this direction the general trend of the coast in Carboniferous times was from southwest to northeast. Let us then first compare series of drillings and sections running in about that direction, in which the top of the Marshall sandstone is between 600 and 700 feet deep.

In the Bay City wells the Marshall is deeper,—in the very deep one at the works of the North American Chemical Co., the Napoleon Upper Marshall extends from 850 to 970 feet in depth. Gypsum is conspicuous about 130 to 200 feet higher, and the Parma or upper salt rock seems to be 360, extending between 490 and 540 feet. Immediately above is a thin stratum of coal near 480 feet. Now we have at Munger, through the kindness of Capt. Blodgett, a record which shows 60 odd feet of sandstone below 348 feet and a coal similarly just above it. This sandstone we may safely take to be the Parma, and we may infer that the top of the Napoleon would be about 700 feet deep. In the upper 350 feet we have not less than four coal horizons sometimes cut out by sandstones, the intervals being 16-90-52 feet. Between 140 and 160 feet are two quite persistent coals about ten feet apart.

Passing now to the old first well of Saginaw put down by the East Saginaw Co., and recorded by H. C. Potter, we find the

---

*Iowa, 1894, pp. 164-171.

Napoleon sandstone at 637 feet, the first strong brines at about 487 feet (gypsum?) the Parma sandstone apparently from 293 feet 9 inches to 399 feet 1 inch, and no coal mentioned immediately above, but from 246 to 256 feet and from 229 to 233 feet were signs of coal. The upper part of the series is replaced by 78½ feet of brown sandstone. While this does not at first appear to match at all we find not far off at Crow Island a black soapstone resembling coal just above the Parma, and 44 feet above it a coal seam. Thus the lower seam is locally absent, and the second seam is the first met in the East Saginaw hole. A boring on C. K. Eddy & Sons' land 700 feet south of Genesee avenue, however, about a mile and one-half farther southwest, near which the Napoleon is struck at about the same depth as around the last well gives coal at 282 feet 3 inches and 203 feet 5 inches, and black slate at 196 feet, etc. The rest is cut out by sandrock. At South Saginaw where an old record with samples shows that the Napoleon is struck at 715 feet, and the Parma 375 feet above at 340 feet, bituminous black shales, occur from 305 to 318 feet—22 feet above, which may replace the lower rider and coal, while higher up at 180 to 200 feet is a coal reported in a great many records, apparently that mined at the Pere Marquette No. 2, the Chappell-Fordney, and the Riverside shafts. In the next seventy feet above are three coal horizons, the intervals in one case being 5-17-31 feet. So, down southeast across the Prairie Farm toward St. Charles, we find the Saginaw seam continues in spots, at somewhere about 190 feet, while above it are at least three coal horizons.

At Garfield there is an old salt well, now flowing. Though the lower salt rock is said to be 800 to 860 feet deep the upper salt rock with a very strong water is from 400 to 450 feet; while between them is said to be much lime rock. A recent well near by found two coals at 130 and 139 5÷6 feet which may be the Verne coals, and a mile and a half east the Saginaw coal comes in at 192 feet. At St. Charles a little farther on the Napoleon is about 700 to 810 feet deep. Below 500 feet is much hard lime rock. Above it is probably the Parma. At 425 feet it is said that there is coal, the lower coal horizon, while the main coal mined in five shafts around St. Charles is the Saginaw coal, from 180 to 220 feet deep. At 128 to 143 feet or thereabouts is quite a persistent vein of sulphury coal about two feet thick, and there are a couple of horizons still higher. (See Plate IX.)

Going into the Owosso district, we find to the northwest of it, comparing Rominger's and Winchell's account of the borings near the Detroit and Milwaukee station[*] and near Six Mile Creek, that there are from two (at 17 and 36 feet) to four coal beds near the surface, with one or two far down at 147 to 180 feet. Going still farther southwest to Grand Ledge, and putting together Rominger's descriptions of the outcrops and the artesian well of the Mineral Spring Hotel with Winchell's description of the explorations near Millett on Sec. 35, Delta T. 4 N., R. 3 W.,[†] we find from two to four coal horizons exposed by the river, and another coal seam some 73 feet below.

It is obvious that these sections do have a general resemblance and parallelism, though they differ in many minor details, which may to a certain extent be merely due to imperfect records. They all lie also in a general northeast-southwest line, roughly parallel to the margin of the basin.

If now we take a series of records lying in a line at right angles to this line, we shall find much more marked difference, so that it is extremely difficult to see the equivalent strata. Take, for instance, the fairly close series of records made by Durand[‡] and the 907 foot and other borings around Corunna,[§] the borings at the D. and M. Station at Owosso and four miles northwest by Mr. Courier on Sec. 57, T. 7 N., R. 2 E., also those of the St. Johns water-works well, and the wells at Ashley, Ithaca, and Alma and St. Louis. We find marked differences and divergences, extending down into the beds below the Coal Measures proper.

In the Durand well, it is probable that the water bearing strata from 174 to 238 feet under the brown shales represent some part of the great series of sandy strata beneath Corunna (on Sec. 22) from 231 to 471 feet.[**] This series seems to correspond to the whole series of sandy strata from 250 feet down to 601 feet in the well at Owosso (Sec. 5, Pl. XLV of Vol. V), which is, however, split by a series of limestones and shales that I take to be the Michigan series. These limestones and shales may in the Corunna well be represented by marginal sandy strata, or not be represented at all according as

---

[*] Winchell, 1861, p. 125; also Vols. III and V of these reports.

[†] Winchell, 1861, p. 124; Vol. III of these repotrs, p. 133.

[‡] For farther details see the last chapter of this report.

[§] Geol. Sur. Mich., Vol. V; see also Rominger's and Winchell's Reports cited, and Lawton's Reports as Commissioner of Mineral Statistics.

[**] The reference in the record to hardpan and stones is probably to a conglomerate, for bedrock is usually struck at from 75 to 175 feet deep, and the water is higher in salt and lower in lime than shallower wells which are certainly in the drift.

the land margin was between Corunna and Durand or between Corunna and Owosso. In any case we have the Corunna sandstone series split once. Then passing from Owosso to St. Johns we find from 264 feet to 435 feet a series mainly of sandstones which must in some degree correspond with those from 250 to 473 at Owosso. Only 28 feet above we come to another sandrock which Winchell might call the Woodville. But the 26 feet of shale can hardly represent all the coal measure series. The shale may be another wedge splitting the great mass of shore sandstone. Then we pass on to Ithaca, which is quite a jump, partly bridged by wells near Ashley (which show down to 217½ feet mainly red sandstone, with coal and light and dark shale in the last few feet), and here we find a little red sandstone and shale near the top, but mainly a series of shales with five beds of dark limestone or black shale which might be taken as equivalent to coal horizons. Underneath this we have 86 feet of light-colored sandstone and then shale again. If we allow for a dip of not more than 15 feet to the mile, and we cannot well allow more, this Ithaca sandstone would correspond to that at St. Johns from 264 feet down, but is much less thick. In that case the St. Johns shale series has swelled and diversified enormously at the expense of the sandstone, and the Ashley well coal stands between the upper and lower sandstones at Ithaca. Then only six miles or so farther on we have at Alma and St. Louis some deeper wells which enable us to see quite definitely where we are. The Napoleon has shrunk from what it was in Owosso—from 65 to 47 feet. The Michigan series above it is characterized by gypsum beds as well as limestone, and is 225 feet thick instead of about 63 as at Owosso. Then we have the Parma sandstone well marked from 710 to 790 feet thick. Now, at 615 feet and 710 feet, are signs of coal horizons. There are two sandstones above it, separated from each other by blue and black shales. Is the lowest only of these three sandstones continuous with the great mass of sandstone to the southeast around Owosso? Probably not, for a dip of fifteen feet to the mile which is probably more than there really is, would make the sandstone at 637 to 675 run into that at 525 to 611 at Ithaca, and the same dip continued would make it split from the great sandstone at Owosso. But the uppermost sandstone, in the Alma well from 500 to 550 feet, and 300 feet down in the shallower St. Louis wells, may be the upper red sandstone of St. Johns and Ashley, and not appear at all around Owosso.

If leaving Alma we pass toward the northeast, i. e., parallel to shore, we find at Midland a record which can be very closely paralleled with that at Alma.*

Turning to the coals; the couple of coals, often workably thick near Corunna, are represented by more numerous coals, and some deeper coals near Owosso, which incline to be thinner. Near the center of the basin we have limestone in their place, and the coal indications appear above another large sandstone, which may correspond to Winchell's Woodville, or may be a split from the Parma, while black shales may represent some of the other coal horizons.

Thus we see indications of the kind of divergence that Keyes' hypothesis would lead us to expect.

The formations above the Napoleon are thicker in the center of the basin. But this is not simply by addition to the top of the series, but full as much by addition and expansions to the bottom of the series. The coal mined around the margin of the basin resembles in chemical character, that is per cent of sulphur and volatile hydrocarbon the higher coals of the center of the basin.

§ 9. Low position of the Michigan coal seams.

Though the limestone underlying the coal series is equivalent to the Maxville in Ohio and the top of the St. Louis limestone of the Mississippi River, the age of the coal beds cannot be directly inferred inasmuch as there is generally an unconformity between it and the beds containing the coal seams. It is possible that near the center of the basin at such points as Midland, Alma and St. Louis the sedimentation may have been continuous, the Kaskaskia limestone being present as well as the St. Louis and the deposition of sediment being uninterrupted until the time of the coal deposits. This was not so at the margins. All the indications are, however, that all our series are low down in the coal measures (Mesocarboniferous), in fact in that section of it known as the Pottsville formation, "Serial conglomerate" or "millstone grit," a part of the series which was once supposed to be below any important coal seams, though it is now known that some of the best coals of the United States, the Lykens valley of Pennsylvania, the Pocahontas and New River of West Virginia, the Sharon, Massillon and Mercer coals of Ohio, belong to this series.

---

*Water resources of the Lower Peninsula of Michigan, U. S. Geol. Survey, 1899, Water Supply paper No. 30. Fig. 11.

The evidence that our coals belong in this the lowest of the formations producing coal in commercial quantities is as follows: The fossil shells have been submitted to Dr. C. H. Girty of the U. S. Geological Survey who writes as follows:

"I have identified the following species:

Central Mining Co., Bay County.
Lingula mytiloides Sow.*
Wenona Mine, Bay County.
Lingula cf. Tighti Her.*
Verne Mine, Saginaw County.
Orbiculoidea sp.
Chonetes flemingi Nor. & Prat.*
Productus prattenanus Nor.*
Productus (*Marginifera*) *muricatus* Nor. & Prat.*
Orthoceras rushense McChes.
Soleniscus sp.
Michigan Mine, Bay County.
Lingula mytiloides Sow.*
Chonetes Flemingi Nor & Prat.*
Productus prattenanus Nor.*
Productus (*Marginifera*) *muricatus* Nor. & Prat.*
Avicula acosta Cox.*
Pleurophorus oblongus Meek.*
Nucula ventricosa Hall?
Trepospira sphaerulata Cow.*
Orthoceras rushense McChes.*
Large nautiloid.
Fish bone.

"The form which I identify as *L. mytiloides* has been so identified by Meek and many other America paleontologists. I am not sure that it is the same as Sowerby's species. The same is true of *Orthoceras Rushense*, the Michigan shells belonging to the form popularly referred, I fear incorrectly, to McChesney species. *Lingula cf. Tighti* may possibly be only young specimens of *L. mytiloides*.

"Regarding the age of this fauna I want to speak guardedly, for we have not been very successful in determining horizons in the Coal Measures by means of invertebrate faunas. The fossil plants seem to be much more reliable. As you observe, the list of species show essentially the same fauna at the only two localities where a fauna of any size was obtained. The invertebrates therefore afford no evidence favorable to subdividing these horizons into more than a single group. The species both as individuals and assemblages are such as are common in the coal bearing strata of Kentucky, Illinois, Iowa, etc., and in a general way indicate the same horizon for the coals of Michigan. This is not very definite, however. The age indicated is certainly older than the Upper Coal Measures of some writers, older than the Nebraska City beds of Kansas, for instance (See Meek's Pal. Eastern Nebraska, etc.). David White thinks the plants indicate Upper Pottsville, if I am not mistaken. We have very scanty *faunas* from the Pottsville and I have no reason to contradict his determination."

The Lingula shale has also been found,—identical in appearance, above the coal (with a Discinisca) at the Valley Coal Mining Company shaft, at the Bay No. 2, at the Wenona Air Shaft and at the Monitor, in all cases as I take it just above the Upper Verne Coal, as it is also at the Michigan Standard Mine. It has been identified at Grand Ledge and on the Rifle River. The richer fauna which occurs just over the lower coal of the Michigan Standard, the lower Verne, in a black bituminous shaly limestone, has also been identified over the coal of the Amelith Shaft of the Pittsburg Co. Rominger reports similar fossils from Jackson (p. 127) and Williamston (p. 135), and again over the upper coal at Corunna (p. 138). Dr. Girty we see does not feel that these species are sufficient for close correlation, and it is well to remember that all the Lingula shales may not be at the same horizon though I am inclined to think it pretty persistent.

Both horizons are at times very close together, for instance in some parts of the Michigan Standard Mine, where the two coals run together toward the east. As Dr. Girty says, there is no indication of more than one horizon in the shells, which indicate quite clearly a marine or brackish fauna associated with those Verne coals. One cannot help being reminded of the upper and lower Mercer coals of Ohio. It is generally noticeable, also, that of the two coals associated with these fossils the upper is darker, less bright, with more charcoal and less pitchy layers, and though there are some sulphur balls it has less sulphur as a whole than the lower more lustrous coal, which contains more sulphur. All these facts indicate that most of the fossils come from one persistent not thick zone, that of the Verne coals.

The plant remains have been submitted to Mr. David White of the U. S. Geological Survey, who has been making an especial study of the remains of this epoch. He reports as follows:*

---

*The fossil lists returned by him are:
STANDARD MINE, SAGINAW.
"1. *Sphenophyllum bifurcatum*, Lx.
2. *Neuropteris.*
3. *Calamites ramosus* Artis.
4. *Stigmaria verrucosa* (Martin Mill.) *S. ficoides* (Brongn).
5. *Caulopteris* indet.
6. *Sphenophyllum cuneifolium* (Sternb. Teill) old form *S. Saxipojufolium.*
7. *Calamites* sp. indet.
8. Fragments of some fruit (Cardiocarpon?).
9. *Asterophyllites* cf. *longifolius* Sternb. (hardly determinable).

"These very incomplete and very fragmental floras interest me greatly, both on account of the fact that hitherto I have never seen else than *Calamites* (of little stratigraphic value) and *Stigmaria* from the coal measures of your state, and by reason of the clues they furnish us to the age of the coals mined at the above named points.

"I have not had time to search for data on the relative positions of the coals or as to their group correlations. From the characters of the little flora I conclude that it can hardly be later than the Lower Kanawha in West Virginia, of the Brookville coal in Ohio and Pennsylvania. In fact, notwithstanding the small number of species I am strongly disposed to regard the plants from the Standard Mine as Pre-*Allepheny*, or at least older than the Brookville coal. On the other hand, they are not older than the Sharon coal.

"The little florula in the nodule from the Owosso Coal Co. points strongly to a place in the Upper Pottsville, i. e., the *Sewanie zone.* There are not enough species to tell whether it is so low as the Sharon coal. I would suggest a comparison of the horizon with the Mercer group. It is not likely to be higher than the group if so high.

"From the above you see that although the material is very fragmentary and the species are few, they indicate for the coals, at

---

10. *Lepidodendron obovatum* Sternb.

GRAND LEDGE.

"The two fragments from Grand Ledge represent the same old early forms. *Sphenophyllum cuneifolium* (Sternb.) Teill."

These are from the north pit of the sewer pipe works, near the level of the upper coal, the upper Verne? From the south pit as reported by the engineer of the works, Dr. F. H. Day, of Lansing, has in his collection.

19. *Lepidodendron lycopodioides* Stb. branchlets with L. *obovatum* Stb. bolsters. *Cordaites borassifolius* (Stb.) Ung. fragments and *Cardiocarpon Cuyahoga* (D. W.)
20. (6) *Neuropteris flexuosa* Stb., close to European type.
21. (16) *Neuropteris* cf. *Harrisi* D. W. (*N. rarinervis* group) with Asterophyllites Sp.
22. Diplothmema Sp.
23. *Lepidodendron obovatum* Stb.
24. Pseudopecopteris (?) or Mariopteris (?), not enough for determination, for obscure nervation."

OWOSSO COAL CO.

I would like to suggest that good material, showing a much greater variety of species might be obtained by splitting off the more shaly external contacts of these nodules. The one which retained the contact shaly layers revealed.

1. Cordaites, probably C. Robbii Dn.
2. *Cardiocarpon ovale* Lx.
3. *C. bicuspidatum* Sterub. var. ohioense D. W.
4. Mariopteris sp. cf. inflata (Newb. Mss.).

ST. CHARLES.

The following forms are from the various shafts at St. Charles, and almost all from that of the Michigan mine (Black Pearl Coal), and immediately above or below the lower coal, the Saginaw seam. A similar Lepidodendron flora is found at the shaft of the St. Charles Coal Co., above and in the splits of the coal.

1. ***Lepidodendron modulatum*** Lx., St. Charles.
2. *Lepidodendron dichotomum* Stb., St. Charles.
3. ***Lepidophyllum cultriforme*** Lx., St. Charles.
4. Macerated fragments of plants with spores and slickensides resulting from collapse of some soft body, probably the fleshy envelope of a fruit.
5. ***Calamites*** cf. ***cistriformis*** Stur, with ***C. Suckowii*** Brongn.
8. *Lepidophyllum cultriforme* Lx. Black Pearl Shaft, St. Charles. This is an old type.
9. Axis of Lepidostrobus cone probably belonging to the same species.
10. Lepidostrobus, apex of, probably belonging to the same species.

11, 12 and 16. ***Lepidodendron ophiurus*** Brongn; St. Charles.

13 and 15. ***Lepidodendron rhombicum*** Stb. (***L. lycopodioides***) Stb., St. Charles.

14. Lepidophloios? decorticated and undeterminable, St. Charles.

7, 17, 18 and 25. ***Stigmaria verrucosa*** (Mart) S. A. Mill. main segment.

26. ***Pseudopecopteris?*** cf. ***obtusiloba*** (Brongn) Lx., J. H. Somers. No. 2 Shaft, St. Charles.

whose horizons they occur, a very low place in the coal measures; probably in the Sharon or Mercer groups for the nodules, while the Standard fossils seem to belong below the Homewood sandstone."

Dr. White also suggests a comparison of the Grand Ledge coal with the Mercer coals. I had already incorporated in the Mss., before receiving his letter, a comparison of the Verne coals with the Mercer coals, and all the evidence goes to show that the Grand Ledge coals correspond to the Verne coals.

The following correlation table may be of service, remembering that the Michigan correlations are very hypothetical as yet. But in a general way I assign the mines as follows:

Upper Verne: Wenona and Handy Bros., upper part; Central, seam not worked; Michigan Coal and Mining, seam now worked; Valley, Monitor, Bay, Wolverine(?), Verne, upper part; Owosso Coal Co., Grand Ledge and Williamston, upper seam.

Lower Verne: Wenona and Handy Bros., lower part; Central, Michigan Coal & Mining, first seam; Amelith shaft; Corunna Coal Co., Sebewaing; Grand Ledge, coal mainly worked; Williamston, Jackson.

Middle Rider, possibly the East Saginaw coals.

Saginaw seam, Pere Marquette No. 1 and No. 2, Standard, Saginaw, Chappell; Fordney, Riverside, Jamestown, Robert Gage, J. H. Somers, No. 1 and No. 2, Black Pearl, St. Charles Coal Co. The coals below this are not worked.

Regarding the abundance of plants in a broad and general way, White, speaking of the Pottsville, says (1891, p. 180): "The fossil contents are also different from those of any sandstones above, since here for the first time in descending the column of rocks do we find Sigillaria and the large Lepidodendra very abundant in the sandstones." Now at the Sebewaing, Saginaw and St. Charles coal mines I have noticed the prevalence of such forms and Calamites and the relative absence of ferns, and Rominger* noted almost exclusively such remains and the Stigmaria or creeping stems of the same plants.

---

*Geol. Sur. Michigan, Vol. III, Pt. 1.

CORRELATION OF COAL SEAMS.

	Pennsylvania.			Ohio.			Michigan.	Mines and Shafts.
District.	Pottsville. D. White.	Lykens Valley.		Earlier Names.	Newberry.	Orton.		Base of Coal Measures proper.
	Upper Intermediate Beds N and M	Twin coal.			Putnam Hill No. 4 coal, Brookville.	Lower Clarion.		
			Seral or Pottsville Conglomerate.	Homewood Sandstone.		Tionesta.	Upper rider coal.	
	Beds J. K. L.	Lykens Coal No. 1						
					No. 3a.	Upper Mercer Limestone.	Lingula shale. Upper Verne coal or Monitor coal.	Most of the Bay county mines, Sebewaing, Verne, Owosso, Grand Ledge, Williamston, Jackson.
	Upper Pottsville formation.				No. 3.	Lower Mercer.	Limestone ?	
						Massillon sandstone.	Lower Verne coal	
	Beds H. I.	(Sewanee zone in Tennessee.) Lykens coals Nos. 2 and 3.		Conoquenessing Sandstone.	No. 2.	Wellston Jackson Hill. Quakertown.	Middle rider.	
	Lower Intermediate Zone.					Massillon sandstone.	Sandstone.	
	Beds E, F, and G.							
	Lower Pottsville.			Sharon conglomerate.	No. 1 Briar Hill, Massillon, Jackson.	Sharon coal. Sharon conglomerate.	Saginaw coal.	Saginaw and St. Charles mines
	Bed D	Lykens coal No. 4. Brookside.					Lower rider. Lower coal.	
	Bed C	Lykens coal No. 5. Big bed.					(Lower beds toward the center of the basin.)	
	Bed A and B.	Lykens coal No. 6.						

In regard to this matter of the predominance of the rush and tree like forms of the lower coal measures we might cite many authorities. For instance, even over in Germany Geinitz divides the coal measures into three groups, which are, beginning at the top:

(1) Strata where ferns prevail: Upper coal measures.

(2) Strata where Annularia prevails,—a form which has a whorl of leaves around the stem, and Calamites,—rush-like form: Middle coal measures.

(3) Strata where Sigillaria prevails, Lower coal measures.

Finally there is a certain similarity in stratigraphy or mode of occurrence, for we find that the law holds for the Michigan coals as well as for the lower coals in general, that they occur in elongate local troughs, probably running each one in a general way toward the center of the basin, but as a whole occurring in a belt parallel to the old shore line and the margin of the basin.

The coal as it occurs in Sebewaing, at Corunna and at Jackson, seems to occur in troughs which are longest east and west or northwest. For instance we find that in the Woodville, the coal rose and ran out toward the Michigan Central track to the southwest. We find similar phenomena noted on other maps of Jackson coal mines. The trough of coal on Sec. 7, Jamestown, near Saginaw, also seems to follow this rule.

Pittsburg coal shaft at Amelith is said to be connected with the Bay Coal No. 2.

The Pere Marquette Mine No. 1 is understood to drain into the Saginaw mine, but to be separated from the Standard to the southwest by a sandstone bar. On the other side it is not far to the northeast before this particular seam plays out.

The directions of the troughs are, however, quite variable, and we cannot yet lay much emphasis on this rule in Michigan. When we turn to the other States we find the evidence more decided. Prof. Sperr says of the lowest Ohio coal, the Sharon and Massillon that it lies in troughs.

Orton describes it as follows:*

"It always lies upon an uneven floor in basins of comparatively small extent. The area of but few of these basins reaches 200 acres of unbroken coal.

"It is everywhere a seam of 'swamp' and 'hills,' the latter rising

---

*Ohio, 1884, p. 156.

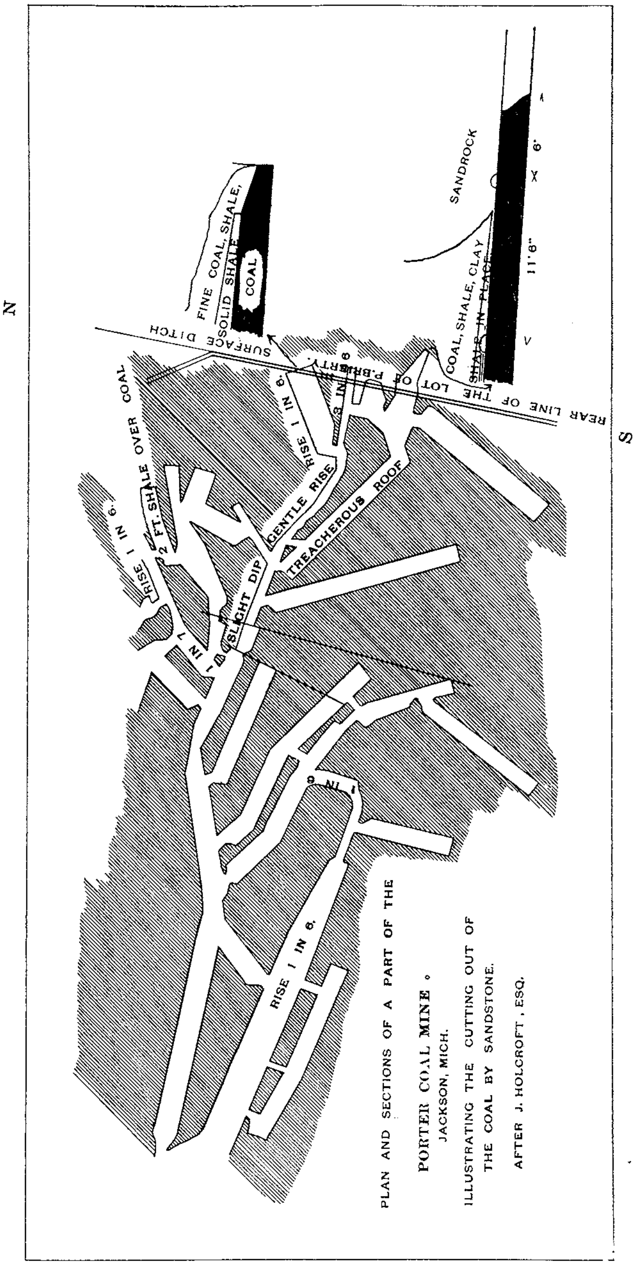


Fig. 5. Plan of part of the Porter Coal Mine, showing irregular mining following trough and stopped by a washout or drift filled channel.

20, 30 or even 40 feet above the lower and more productive portions of the seam. In ascending these hills the coal rapidly loses height as a rule, and frequently disappears.

(p.775.) "The Massillon coal occurs in lenticular areas of 30 to 70 acres, thickest at the center or axis of the swamp."

Again Bain and Leonard say (preliminary abstract of a paper before the Geol. Soc. Am., Aug. 25, 1898):

"The lower coal measures of the western interior field are marked by non persistence of strata. The upper measures are more regular. Between the two is a series partaking of some of the characteristics of each."

The same observation is made of the Indiana fields by Ashley in the 28th Annual Report, pp. 89 to 90.

And finally White remarks (1891, p. 180):

"The coals of the Pottsville series are persistent and valuable only around the margins of the Appalachian coal field."

It remains to be seen how far the coal strata of the center of the Michigan basin will show marks in their stratigraphy or plants of any later origin.

The two Verne coals may be traced, partly by stratigraphic comparison of record after record, partly by their chemical character, as coking coals, the lower one sulphurous, partly by their association with the Lingula shale, and calcareous beds full of marine fossils especially Productus, through the Bay county, Saginaw and Saint Charles fields, as I believe also in Owosso and Corunna, Williamston and Grand Ledge to Jackson.

If these are, as I believe, nearly equivalent to the Mercer coals, inasmuch as around Bay City they appear some 700 feet above the top of the Marshall sandstone, and may be traced more than half way to Midland with very little dip, it is quite possible that the 700 feet or more of strata above the base of the Parma sandstone at Midland belong wholly to the Pottsville formation, the extra thickness over sections elsewhere being produced by additions at its base. This is made more easy to believe, owing to the thick series of strata which Keyes has found elsewhere between the eocarboniferous limestone and strata of the age of the Pottsville.

Thus it seems to me at present most probable that the coal which occurs at about 136 feet around West Saginaw is at the same horizon as the coal at 85 feet around Sebewaing, and but little later formed as the marginal floating bog gradually crept out over the surface of the comparatively shallow arm of the sea, whose bottom was slowly sinking, which was, however, yet more rapidly filling up.

Keyes has recently published a paper on the Trans-Mississippian coals and their correlation.*

The Pottsville formation and the best known part of the Michigan series correspond to his DesMoines series. The unconformity between them and the underlying eocarboniferous limestone, which he calls Mississippian, and possibly also some part of the lowest beds in the center of the basin, represents his Arkansan series.

---

*Engineering and Mining Journal, June 1, 1901.

CHAPTER IV.

ANALYSES AND TESTS OF COAL.

§ 1. Introduction and acknowledgments.

This subject which in the original report, issued in the Michigan Miner, was relegated to an appendix is treated more fully here. Numerous facts have accumulated in the meantime, the important series of tests made for us by Mr. H. J. Williams have been completed and we wish not only to help those who are having or should have analyses made to understand their value, but also to remove an impression which has been too prevalent, that Michigan coal is all of the same quality and that poor. Michigan coal is not all of the same quality and by no means all poor. Some of it (the Verne seams) is coking, some of it is not, some sulphurous, some (the Saginaw seam) not, and the heating power varies. Finally, Mr. Williams' results have a wider value, in fixing certain relations between heating power and analysis, which hold approximately true in Michigan at any rate.

I am indebted to Prof. F. S. Kedzie, of the Michigan Agricultural College, Lansing; Mr. H. J. Williams, of 161 Tremont St., Boston, Mass., for valuable help in the preparation of this chapter, and also for analyses and tests to F. F. Bradley of the Alston Manufacturing Co., A. N. Clark of the Alma Sugar Co., and C. H. Hilton, of the Agricultural College, Prof. C. A. Davis, of Alma, Geo. B. Willcox, M. E. of Bay City, and others.*

The following references will give the latest results and put one on the track of earlier works on this subject.

(1) Phillips, H. J. "Fuels, solid, liquid and gaseous, their analysis and valuation;" London, Crosby & Lockwood, 5 sh. This is practically reprinted in the "Engineering Chemistry" of the same author and publisher, 1894.

---

*Prof. Weil of the Mechanical Department of the Agricultural College checked Plate II.

(2) Lord, N. W., and Haas, F. "The calorific value of certain coals as determined by the Mahler Calorimeter." Transactions of the American Institute of Mining Engineers, February, 1897 (Chicago Meeting), Vol. XXVIII, p. 259. In this same volume this paper is discussed by Wm. Kent and compared with earlier results, p. 946.

(3) Slosson, E. E., and Colburn, L. C. "The heating power of Wyoming coal and oil." Special bulletin of the Wyoming University, Laramie, gratis. January, 1895.

(4) Kent, William. "The calorific value of fuels," in Mineral Industry for 1892, p. 97, an annual published by the Scientific Publishing Co., New York, $5.00, also in Vol. VIII, for 1899, pp. 124 to 129.

(5) Fritzsche Dr. P. "Die Untersuchung und Bewerthung der Brenn stoffe," Leipzig, 1897.

(6) Willcox, Geo. B. M. E. "Coal analyses—Their Objects and Uses." Michigan Miner, Vol. No. 4 (March 1, 1899), p. 19.

(7) Hale, R. S., and Williams, H. J. "The calorific Power of Weathered Coal." Trans. Am. Soc. of Mech. Engineers, December, 1898, Vol. XX, No. 798. Carpenter.

(8) Kerr, C. V., Trans. Am. Soc. of Mech. Engineers, Vol. XXI, No. 841, December, 1899. "The Berthier method of Coal Calorimetry."

(9) Christie, W. W. Trans. Am. Soc. of Mech. Engineers, Vol. XIX, No. 765, December, 1897, Boiler tests: Classification of data and plotted results.

(10) Hilton, C. H. "Sulphur and Iron in Michigan Coal." Michigan Miner, Vol. II, No. 9 (August 1, 1900), p. 9.

(11) Report of Committee on Revision of Standard Coal for Conducting Steam boiler trials, Vol. XXI. Transactions, Am. Soc. of Mech. Eng., No. 827 (December, 1899), and Discussions of same, No. 828.

(12) A new coal calorimeter by R. C. Carpenter; same transactions (June, 1895), No. 653.

There are also papers in Mines and Minerals, etc.

For the sake of those who have the works accessible, we may note that in the tenth census report (Gooch, Vol. XV, p. 775), and in the State Geological Survey reports, are many analyses, etc. (e. g. MM. of Pa.; Ohio, 1870, p. 236; Illinois, 1886, Vol.; Arkansas, etc.)

§ 2. Methods of testing.

Coal is principally used for producing heat. Its heat is mainly used for producing steam, and as thus used, the quality of the coal is naturally measured by the amount of water which it will convert into steam. In order to make this a definite quantity we must specify, however, how hot the feed water is, how hot the steam is and what the barometric pressure is. These will vary in different tests and reductions must be made accordingly, which are briefly noted below but are described more fully in mechanical text-books.

Whatever method of testing and of stating the results thereof is used, the results will be most easily understood by comparing them with some coal with whose behavior and, quality one is familiar. For this reason, we have included in the reports of the tests, those upon a number of coals mined outside the state, but commonly used within it, so that the results may be interpreted by comparison with them.

The methods of testing are as follows:

(1) Direct boiler tests, in which the results are stated in pounds of water evaporated into steam, per pound of fuel or per pound of combustible. The latter is generally obtained by subtracting the amount of ash,* and properly also moisture from the coal.

These are often tests of the boilers as well as of the coal.

(2) Tests of the coal, obtained in the instruments known as calorimeters, in which the amount of heat given off in burning a quantity is determined by absorption of the heat in water and measuring the rise produced. The results of these tests are stated in calories, i. e., the number of units (kilograms) of water which one unit (kilogram) of fuel will raise 1° centigrade, or in British Thermal Units (B. T. U.), i. e., the number of units (pounds) of water which one unit (pound) of fuel will raise 1° F. It is supposed to take 965.7† of the British Thermal Units to convert a unit of water at boiling point, into steam of the same temperature under average barometric pressure at sea level.

Pure carbon is supposed to give from 8080 to 8140 calories, that is 14,544‡ to 14,652.2 B. T. U. so that one pound might convert 15.1 to 15.2 pounds of water already boiling, into steam. Under ordinary circumstances of feed waters, etc., about half that amount per pound of combustible is obtained.

---

*If the coal contains much oxidizable iron, etc., this may give too low percentage of combustible.

†Or as 1 calorie = 1.8 B. T. U., 536 calories. See Plate II.

‡Fabre & Silberman, 14,544; Berthelot, 14,647.

(3) The heating power may be very closely computed from what is known as an ultimate analysis and Dulong's formula, which is explained below, gives as good results as any:

(Heating power in B. T. U.)=146 × % carbon + 620 × (% hydrogen — $\frac{1}{8}$ oxygen) + 40 × % sulphur.

(4) The heating power has also been estimated in various ways from what is known as a proximate analysis, but the formula which seems to give as good results as any of them for our Michigan coal* is, heating power in B. T. U. = 146.6 (× % combustible) + 40 (× % sulphur).

(5) The heating power is sometimes computed from the reducing or deoxidizing power of the coal. This is known as Berthier's method and for a unit of fuel we recommend for our Michigan coals to apply a formula which I have derived on a following page: Heating power in B. T. U. = 423.4 (× amount of lead reduced) × 650.

The last terms in these last two formulæ are fairly small, and the formula practically implies that the heating power is nearly proportionate to the % of combustible regardless of the relative proportions of fixed and volatile carbon. This is not accepted for coals in general and I do not wish to propose to extend these formulæ, except for our Michigan coals or so far as tests confirm them.

We will now proceed to consider these various methods of testing in detail after we have first considered the very important question how we are to get as fair a sample as possible of the coal for testing.

§ 3. Sampling.

A single lump is quite likely to be misleading. The heavier sulphur, slate and dirt tend to accumulate at the bottom of a pile, and in the finer stuff or slack. It requires some care to get a fair sample. Samples from well drillings are usually mixed with more or less clay from above. If that is washed out, as it usually is, it is nearly impossible not to wash away at the same time a certain amount of the pyrite (sulphur and ash), which occur in the coal. "At least five pounds of coal should be taken for the original sample, with care to secure pieces that represent the average, say the A. C. S. committee." In taking samples of worked seams, my own practice is to take about 25 pounds, evenly distributed from top to bottom of the worked seam. Very commonly in Michigan

---

*Provided the moisture is thoroughly driven out.

immediately above the main seam, is from 3 to 8 inches of poorer "bone coal," "cannel coal or "slaty coal," sometimes improperly called black jack. This and the larger masses of pyrite will be kept out of the coal in mining and shipping, so far as possible, but more or less gets in especially in the run or slack. Care should therefore be taken to say whether these and slate partings were included in the sample or not. Thus the coal as shipped may possibly be somewhat better than a fair sample of the seam taken as above. It may also be poorer. My large samples were sent to H. J. Williams. He has some very ingenious arrangements for getting a true fractional sample. In general principle the material is run through a crusher and falls upon a sloping screen the bars of which are, however, hollow upwards and catch and conduct to one side a certain percentage of the material. The material which Mr. Williams did not use was returned to me and then fractioned very much as described by Fritzsche, and is preserved in sealed glass jars containing half a pound to a pound, for distribution. The samples when shipped to Williams and back again were not, however, in tight jars, but in stout paper bags inclosed in cloth sacks, and then boxed or barreled, so that there was opportunity to dry, and lose all superficial moisture.

Mr. C. H. Hilton's analyses show some desiccation that came since or in the later finer grinding of the material. The material thus preserved in jars is about pea or rice size.

The method of sampling recommended by Fritzsche* is as follows:

"Sampling is best done by an experienced hand as follows:

"From every cage or bucket of coal which is to be tested a shovel full is thrown into a separate bin. At the end of the sampling, the large pieces of the sample (which will weigh from 50 to 100 lbs.) are broken to nut size and the samples well mixed on a large floor or plate and the top of the pile pressed flat. Then with a smaller shovel, a narrow section is taken straight across and another at right angles. This smaller sample of from 5 to 10 lbs. is best sent in a tin lined chest to the analyst, who crushes still further and proceeds as above indicated two or three times over to get a good average sample of 300 grams weight, in pieces the size of a millet seed. This sample is kept in a glass jar with tight glass stopper and used for determination of moisture after a quarter of the same is taken off in the same way and crushed to a fine powder and put in a separate bottle, for the rest of the analysis."

---

*1897, p. 48.

§ 4. Determination of moisture.

The first step in either an ultimate or proximate analysis is the determination of moisture. This determination is also commonly made in calorimeter* and other tests. For the moisture in a coal obviously does not help its heating power, and in the same fuel is liable to a good deal of variation depending upon the time it has been kept and the surroundings.

In this determination a sample of coal is first weighed, and then thoroughly dried. Gooch dried his sample over sulphuric acid 48 hours, weighed it, and then suspended it over water, but not in touch with it, 48 hours more and weighed again. The more common method is to heat nearly to boiling for about an hour (Phillips, and Lord and Haas, one hour at 100° to 105°C., Williams 45 to 60 minutes at from 105° to 107°C.), and the loss of weight is given as moisture or H_2O. To get comparable results the same methods must be employed. Probably it will be best to follow the rule of the A. C. S. committee: "Dry one gram of coal in an open porcelain or platinum crucible at 104° to 107°C., for one hour, best in a double walled bath, containing pure toulene, cool in desiccator and weigh covered."

Prof. Kedzie believes that more uniform results are obtained by drying the finely powdered material in vacuo over sulphuric acid.

It would be more accurate, but more expensive to collect the moisture and weigh it.

Kent has called attention to the fact that on heating the coal the weight decreases to a minimum, somewhere about 250°F., and then increases slightly (as the pyrite oxidizes?), and no loss of volatile matter occurs until about 350°F. His results have been confirmed by Carpenter and F. S. Kedzie.

This moisture is not merely wetness on the outside of the coal, although such would be included if there. But the samples which were sent to Mr. Williams, were so packed that they had a good chance to lose any superficial wetness, and after being returned from him were stored for sometime in a dry room, before being divided and sealed. Mr. Hilton remarks of them, that even then, while "the coals are to all appearances perfectly dry, yet when they are subjected to a temperature of 100°C. for half an hour they lose 5 to 10 per cent of their weight." So also Mr. Thomas Pray remarked regarding the amount of moisture in the sample whose

---

*Especially in using the Parr Calorimeter, see p. 73.

analysis he furnishes (Table I, Nos. 3 and 4), that it was not superficial moisture. Almost all of the Michigan coal is under strong hydrostatic pressure, except that around Grand Ledge. Coal is also somewhat hygroscopic. The lightness of the coal seems to be partly due to the moisture.

Especial care must, therefore, be taken to drive off all the moisture, and I think that many analyses of Michigan coal have failed in this respect. In boiler tests, for instance, it has been a common practice to set a pan of the coal not over three inches deep on the hottest part of the brick work for twelve hours. This method will not be at all satisfactory for Michigan coals. It gets rid of the "surface" or "accidental" moisture, but not the "characteristic" moisture, which may be sometimes reabsorbed from the air after being driven off by gentle heating, and is high in our Michigan coals generally.

In some coal high in sulphur and clay there is reason to believe that the low moisture returned is an analytical error, as will be later explained.

§ 5. Determination of ash.

Even in the common use of boilers it will be found of great practical benefit from time to time to make a trial run under average conditions, weighing the amount of feed water and coal used and of ashes removed, leaving the plant as nearly as possible in the same condition as found. Some results of tests of this character at the Lansing Municipal plant are given below (pp. 72 and 73). Tests of percentage of ash are almost invariably made in connection with any heating tests as well as ultimate and proximate analyses.

The A. C. S. recommend determining this from the sample left after determining moisture, thus: "Burn at first over a very low flame with the crucible open and inclined till free from carbon," that is, until further burning makes no alteration in weight. If properly treated this sample can be burned much more quickly than the dense carbon left from the determination of volatile matter.

The further determination of the constituents of ash is like the analysis of any rock, and several analyses are given by Phillips.

A complete analysis of ash is quite expensive, and the components determined are those usually determined in rocks, SiO_2, TiO_2,

Al_2O_3, Fe_2O_3, (originally either sulphide, carbonate or oxide of iron) CaO, MgO, Na_2O, K_2O, CO_2, P_2O_5 (important in cokes for iron smelting) and H. J. Williams analyzes the ash for sulphur at any rate, in order by subtraction to get the volatile sulphur. It is well to analyze the ash in case the coal is to be used in Portland cement manufacture.

The oxidation of the iron and the partial separation of the CO_2, where the ash is largely $CaCO_3$, as Bradley reports to be true of a St. Charles sample, and Mr. Hess of a sample from the Corunna Coal Co., introduce errors in the process of burning, making the ash more or less than the substance from which it was derived in the coal, but they are probably quite small, though I have seen crystals of gypsum on the surface of the Michigan coal, and veins of calcite and anhydrite. In very sulphurous coals as in No. A6 it may be apparent that if all the sulphur came from FeS_2, all the ash must have too. For a given per cent of sulphur present in marcasite FeS_2 we shall have $\frac{7}{8}$ as much iron or 10÷8 as much Fe_2O_3 in the ash. The ash will be greater than it should be by an amount equal to $\frac{3}{8}$ of the % of S. If half the sulphur remained after driving off the volatile combustible, the per cent of fixed carbon found by subtracting the % of ash from the residue left after driving off the moisture and volatile carbon will be $\frac{1}{8}$ of the S too large.

For instance in Williams' analysis of the Michigan Standard Coal Mine below (No. A9), if we suppose, as Hilton's work makes likely, that the volatile S is all in pyrite, this must have contained 4.98% Fe, equivalent to (4.98×10÷7) 7.11 Fe_2O_3 in the ash. Hence the ash (8.26%) found by analysis was almost wholly iron oxide. Instead then of the coal having an analysis of 6.09% moisture, 39.59% volatile combustible (including $\frac{1}{2}$S) 46.06 fixed carbon, and 8.26 ash, it should really be, supposing that the S were half driven off with the volatile matter, 6.09% moisture, 36.75% volatile hydrocarbon not including S, 10.66% pyrite, 1.15 ash and 46.35 fixed carbon.*

Hilton's work† indicates that the iron and the volatile sulphur are practically so closely connected that one may be inferred from

---

*In some older forms of proximate analyses the sulphur was subtracted from the volatile matter or in part from the volatile matter and in part from the fixed carbon, half from each by some chemists or 60% from the volatile matter and 40% from the fixed carbon. This is not at all to be advised, since the proportion of sulphur which goes off with the volatile matter is uncertain, and varies not only with slight differences in manipulation, but also according as there is more or less of sulphur as sulphates in the ash.

†Reference on page 52.

the other, since they are in the same proportions as in pyrite, i. e., 7 of iron to 8 of sulphur. Thus an analysis for iron, one of the most simple and rapid of chemical operations, would be very nearly as instructive as the much more troublesome test for S. His results are given in Table D of analyses below and are shown graphically in the figure accompanying.

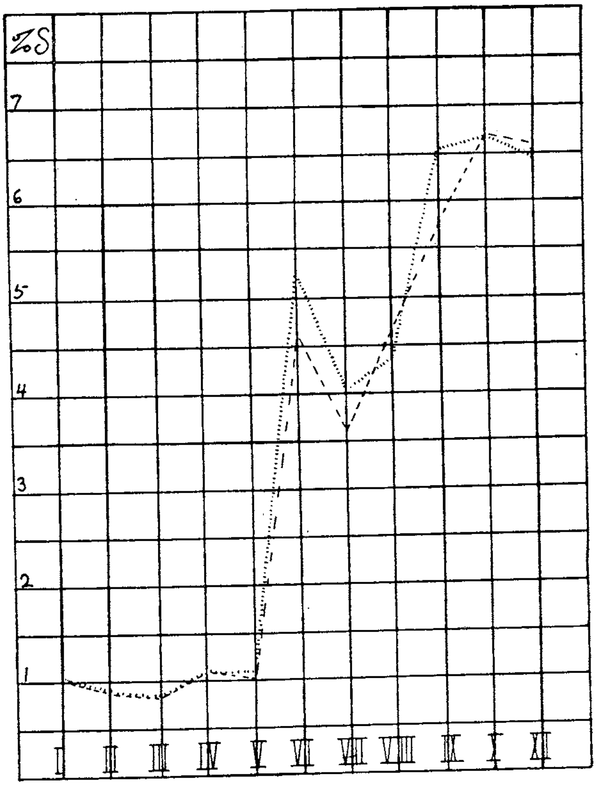


Fig. 6. After Hilton, illustrating the connection between the sulphur and iron in the coal analyses of Table D. The line with dashes connects the percentages of S directly determined, the dotted line, the percentages of S computed as 8÷7 of the iron.

§ 6. Determination of sulphur.

There is one constituent of so marked effect on the quality of the coal that an especial test for it is, and should be usually made, even in a proximate analysis, unless the method above suggested of estimation from the iron may in some approximate work prove satisfactory, and that is the sulphur.

Usually the coal containing the sulphur is burned in a closed vessel or combustion tube with one or another oxidizing agent to ensure complete oxidation to sulphates, and no escape of gas, and then the resultant amount of sulphates determined. If the amount of volatile sulphur* (sulphur combined as pyrite) is required the amount of sulphur or sulphates in the ash may be found and then subtracted from the total sulphates, but as the analyses show (Table A) the sulphur of the ash is usually only two or three tenths per cent.

This is the process adopted by Williams, who uses the method of analysis usually followed, known as Eschka's, thus described by Fritzsche:

> "Weigh I gram of the same coal powdered in a platinum boat holding 30÷50cc. Add $1\frac{1}{2}$ grams of previously prepared mixture of 2 parts sodic carbonate and one part of magnesia, thoroughly mix with a platinum spatula and heat the crucible over a Bunsen burner turned down to a small flame so that only the bottom of it is faintly red, one hour, frequently stirring with a platinum rod. The reagents should be free from sulphates, which is frequently not the case, especially with the magnesia, even though it is bought as chemically pure. If the amount of SO_3 in the magnesia is known, a corresponding correction may be made in the result. To make sure of the complete oxydation of the organic matter as well as any sulphides that have been formed, add to the partially cooled contents of the crucible a few decigrams of finely powdered ammonium nitrate NH_4NO_3, and heat once more in a covered crucible. Shake out the contents when cool into a beaker, wash several times with distilled water, and free any small quantities that stick to the vials, add to the wash water about 100cc distilled water to the beaker and boil about ten minutes. Put the cooled off solution with that which is undissolved in a 250cc measure glass. Fill up to the mark, mix and use 200cc of the filtered solution to determine sulphuric acid as usual."

Williams oxidizes with bromine in the presence of a little HCl, and precipitates with $BaCl_2$ forming $BaSO_4$.

13.789% of the $BaSO_4$=%S.

Fritzsche says that it is decidedly not advisable in order to insure complete oxidation that the sodic carbonate and magnesia be brought to fusion for some minutes, since in that case the silica of the ash is more or less dissolved and must be removed with much loss of time before the sulphuric acid determination can proceed.

Mr. Hilton proceeded as follows, using a modification of Eschka's method:

---

*This will not be the same as the amount of sulphur volatilized in the volatile matter necessarily, for there is likely to be some fused pyrite left in the coke.

"A weighed portion of coal (1-1.5gr.) is intimately mixed with five times its own weight of sodium carbonate c. p. and placed in a flat bottomed platinum dish. The sample thus prepared is placed in a muffle, which, though hot, is still black. The furnace is so regulated that in half an hour's time the muffle will have reached a clear cherry red color. This degree of heat is maintained for another half hour, at the end of which time it is found that all the sulphur as well as all the carbon is entirely burned. The sulphuric acid displaced a portion of the carbonic acid of the carbonate, thus forming a soluble sodium sulphate. The remainder of the process is identical with Eschka's method.

"The sulphuric acid in the ash is made soluble by boiling the ash in a strong solution of sodium carbonate. The determination of the sulphur is then the same as in the whole sample."

Fritzsche also describes a method by which the combustible sulphur may be determined directly, the combustion taking place in a current of oxygen passing through a tube in which the coal lies in a platinum boat and is heated, the products of combustion being caught by being passed through two Peligot tubes filled with bromine and dilute HCl (or as he suggests H_2O_2 may be used if it can be obtained free from sulphuric acid). At the end when no more brightening glow of combustion can be obtained from the coal, the contents of the two tubes are thoroughly washed into a beaker, heated until bromine fumes disappear and into the hot solution of about 150 to 200cc, 2cc of a 10% $BaCl_2$ solution added. After a short boiling the precipitate is allowed to settle and the liquid above poured through an ashless filter, water is added to the precipitate and boiled again, and the precipitate brought upon the filter and washed with hot water until the wash water ceases to react for chlorine. The moist filter paper is put into a platinum crucible (folded together a little) and then burned to whiteness over a large Bunsen flame in a weighed open crucible. If the amount of $BaSO_4$ is but small the amount of the sulphate, which is reduced by the organic matter of the filter paper, is completely oxidized again after a short heating. If the precipitate is large and lumpy it may be well to moisten with some drops of ammonia sulphate c. p. and heat again.

§ 7. Ultimate analysis.

The ultimate analysis consists in the determination beside the ash, sulphur and moisture already described, of the carbon (not including the carbon present as CO_2 in the ash), the hydrogen (not including that in the moisture), the nitrogen, and (*by difference generally*) the oxygen.

The coal is burned in a glass combustion tube as in the determination of volatile sulphur, in an atmosphere of pure oxygen, with copper oxide and lead chromate, and the products of combustion are collected separately, by being passed through a series of tubes: carbon as CO_2 absorbed by KOH, hydrogen as H_2O absorbed by $CaCl_2$ or H_2SO_4. Nitrogen is determined volumetrically or by Kjeldahls' method, or the total acid product may easily be obtained in connection with the Bomb calorimeter test described below, and is sometimes ascribed to nitric acid. This would be quite inaccurate for our sulphurous Michigan coals, but if the sulphur is known the nitrogen may be computed.

Such an ultimate analysis costs about $15.00 or $20.00 and the heating power can be computed from it quite closely by Dulong's formula, as discussed below. It is to be noted that since the oxygen is determined by difference, any error in the other determinations will be reflected in it. If, for instance, the determination of ash is too large* that of oxygen will be too small.

§ 8. Proximate analysis—volatile combustible.

In addition to the determinations of ash and moisture, only one further determination is used in what is known as a proximate analysis, that of the volatile matter or volatile combustible as it is called. The endeavor is to estimate the hydrocarbons with part of the sulphur or that part of the coal which makes gas.

Comparable analyses of volatile matter must follow the same procedure, as various times and temperature give varying products and varying amounts of residue.

The A. C. S. committee procedure is:

Place one gram of fresh, undried coal in a platinum crucible, weighing 20 to 30 grams and having a tightly fitted cover. Heat over the full flame of a Bunsen burner for seven minutes. The crucible should be supported on a platinum triangle with the bottom 6 to 8 centimeters above the top of the burner. The flame used should be 20 to 25 centimeters high and burning free, and the determination made in a place free from draughts. The upper surface of the cover should burn free, but the lower should remain covered with carbon. To find volatile combustible matter subtract the percentage of moisture from the loss found here, the residue, if coherent, is the coke.

---

*Through oxidation of the iron of pyrite, etc. If the earthy matter of the coal consisted largely of carbonates the error might be the other way.

Lord and Haas heated $3\frac{1}{2}$ minutes over a Bunsen burner, then $3\frac{1}{2}$ over a blast lamp. The difference between this and the ash is called the fixed carbon.

It is clear that a proximate analysis is but a series of weighings and heatings. Thus:

	Loss is	Residue is
First heating to a little above boiling (under 250° F.).............	moisture........	dry coal
Second heating, seven minutes until the smoky yellow flame ceases..	volatile...... combustible..	coke
Third heating, until there is no more loss..........................	fixed.......... carbon.......	ash

Practically, however, it is found best to find the moisture and ash from one sample and the volatile carbon from another, while the fixed carbon is estimated by difference. It is obvious that the sum of the percentage of the different components being always 100, if one is too large, for instance the ash, owing either to the fact that the coal was not completely consumed, or that the ash contained iron which was oxidized, then some other component like the fixed carbon must be too small.

The proximate analysis is much cheaper and simpler than the ultimate, and if a determination of sulphur is also made it may give us practically almost as much information as the ultimate. The heating power cannot be told from it quite so reliably in general, though from any one seam and district a formula may be obtained nearly as good, and as will be shown below, the formula,

Heating power in B. T. U. = 146.6 (total combustible; i. e., fixed carbon and volatile combustible) + 40 (per cent of sulphur), gives as good average results for Williams' analyses as Dulong's formula applied to the ultimate analysis.

§ 9. Nature of the volatile combustible or gas.

The volatile combustible consists as we have said mainly of illuminating gas together with certain impurities including much of the sulphur.

The hydrogen sulphide and carbon bisulphides, ammonia and other impurities of a tarry nature which are distilled in the volatile matter are deleterious to a fuel or illuminating gas, though of some value in themselves, and must be got rid of so far as may be. They cannot be eliminated entirely. To this end the sulphur is absorbed by quicklime, or by fresh ferric hydrate spread on sawdust, which recombines with the sulphur to form sulphide of iron once more.* It is common to estimate the purity of the gas by the number of cubic feet which will be purified by one bushel of lime. In Analysis I1 Pennock found per ton of 2,000 lbs. 19.16 lbs. of ammonia sulphate = .958% = 1.373 × the percentage of ammonia; also 110 lbs. of gas tar = 5.5% and 10,600 cu. ft. of gas. According to Winchell the Jackson coal yielded 8,000 cu. ft. per ton of 2,000 lbs. and 30 to 40 bushels of coke.

The ammonia is used extensively in producing soda from salt by the Solvay process, and in domestic use. The gas weighs from half as much as air up, or about 30 cu. ft. to the pound.†

The following is a commercial report on a test of the Saginaw coal in gas production, made at the Keystone Tumbler Company, Rochester, Pa., in the Duff Continuous Water Sealed Gas Producers:

"Sixty-one tons of Saginaw coal operated the plant for six days continuously; no other coal used on the premises during the time of test.

"With Pittsburg coal, they used on an average of twelve tons every twenty-four hours to operate the plant, showing that sixty-one tons of Saginaw coal accomplished the same work as seventy-two tons of Pittsburg coal.

"At the end of the six days' run, there was less deposit of tar and gummy substance on the flues than is usual with local coal for the same length of time.

"There was less accumulation of clinkers and ash than with local coal for the same length of time.

"Comparison of Saginaw coal with best grade of Pittsburg coal, by analysis; from Pere Marquette No. 2 Shaft."

	Saginaw.	Pittsburg.
Moisture	1.98	.20
Fixed carbon	53.20	55.69
Volatile combustible matter	43.49	39.54
Ash	.97	4.05
Sulphur	.394	.52

Wuth & Stafford, who made the analysis, say:

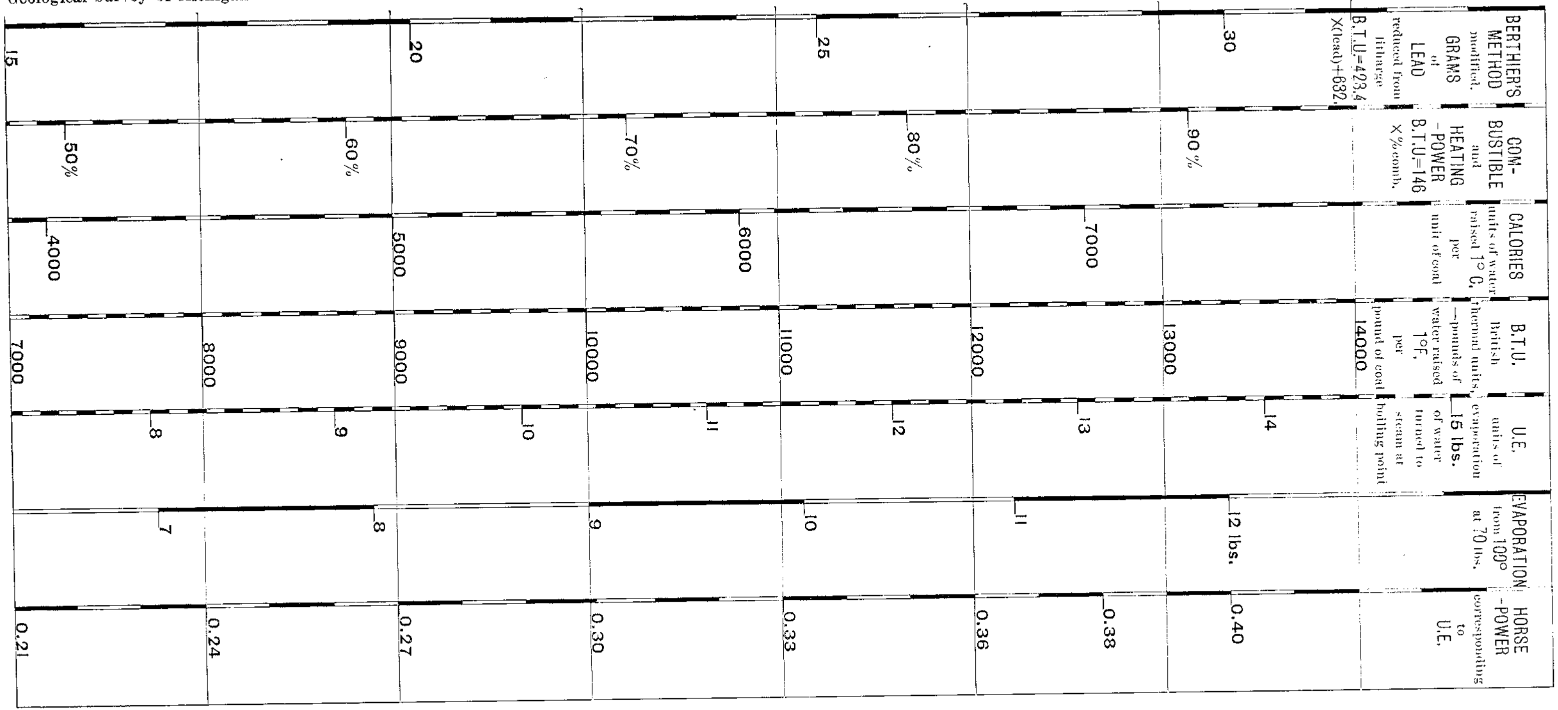
"This is undoubtedly a good steam coal and we think it will do very well for producer gas. It requires a little different work from our Pittsburg coal and will take a little practice to find how to handle it."

They mean by this, that because of the high percentage of moisture, steam and air injected into the producers must be regulated differently.

---

*Ferric hydrate is a waste product from purifying brine and sawdust a waste product of lumber. So that although the quicklime process is the more usual one, one would think the latter process might be economically employed at some points in Michigan.

†For analyses of gas, etc., see Mineral Industry, 1899, Vol. VIII, p. 147.



EQUIVALENT EXPRESSIONS for HEATING POWER of AVERAGE MICHIGAN COAL

EXPLANATION OF PLATE II.

This Plate is intended to illustrate the equivalences in various expressions for the heating power of the coal, and also the heating power to be expected of the average Michigan coals, if it contains a certain per cent of combustible, column 2, or a certain reducing power, column 1.

For instance we see that if the burning of a pound of coal can raise 11,000 lbs. of water 1° F. the burning of one gram of coal can raise about 6,110 grams of water 1° C. A pound of such coal can then turn 11.4 lbs. of boiling water into steam, or 9.9 lbs. if the pressure is 70 lbs. to the sq. in. This is equivalent to a third of a horse-power per hour. For each horse-power per hour therefore if we use coal of 11,000 B. T. U. grade we must use three (times a factor which depends on the efficiency of the boiler and engine and is usually not less than two) pounds of coal. Such a coal would be a very low grade one for a Michigan coal, containing only 75.3% combustible, i. e. 24.7% of moisture and ash. Michigan coals generally run 13,000 to 14,000 B. T. U., that is the combustible is near 90% and the amount of moisture and ash not far from 10%. A gram of such coal we see from column 1 should reduce not far from 30 grams of lead from litharge, while the lower grade (11,000 B. T. U.) coal should only reduce 24.5 grams, supposing it to have the average composition of Michigan coals.

The superintendent of the works where the test was made says: "The coal is better than we get here.

"We are of the opinion that the coal is suitable for gas making purposes and that it can be used with economy.

"(Signed) H. L. DIXON,
"No. 3 Wood Street,
"Pittsburg, Pa."

It will be noted that while they speak of the "high percentage of moisture" in the body of their letter, the analysis shows much less moisture than many of our analyses, but on the other hand more volatile matter. This is almost certainly due to a difference in analytical treatment.

Of these so called impurities of the gas, the coal-tar matters have, however, a very considerable value in themselves. In one case I was informed that a company offered to pay all the expenses of altering a coking plant which was letting them go, and guarantee a good price for the coke product, finding their profit solely in the coal-tar matters.

§ 10. Coke.

The residue after driving off the volatile matter or gas, if coherent, is called coke. But, according to the time, quickness and severity of the heating and amount of ash will more or less of the carbon and sulphur be retained. The coke contains, of course, all the ash.

The most called for coke should be clear, bright, hard, open textured, with but little sulphur and phosphorus, especially for iron manufacture. Its porosity may be tested by weighing it dry and then when saturated with water.

I have seen some nice looking coke made as an experiment from the Wenona coal, and it will be noticed that Mr. Williams reports a number of the coals as the coking coals. The coals which are thus coking are not, however, the lowest in sulphur, but as Dr. Koenig has remarked, by proper handling a large part of the sulphur may be driven off, so that but little will appear in the coke. Ordinarily only about half of the sulphur is driven off, FeS_2 being changed to FeS. Tests have been made of the coke from a number of the Bay county mines. For instance, samples from the Valley Mining Company's shaft at Salzburg are reported to have yielded 39 bushels of coke per ton at the Bay City gas works. The coking coals seem to be the Verne coals.

§ 11. Heating power—practical test.

The full amount of heat that can be obtained from coal in a physical apparatus cannot be practically obtained under a boiler, where the combustion of coal is not perfect, as when there is incomplete combuston to CO, instead of CO_2, 11÷16 is lost. Also the gases escape hot and every per cent of moisture or of hydrogen burned to water in the coal that escapes as steam carries away much heat with it. The percentage of heating power actually realized depends not only on the coal, but on the perfection of the furnace draft and boiler. It is the highest where unburned air forms about one-third of the chimney gas, and has been found as high as 55% to 65% of the theoretically possible. For instance 7 Saarbruck coals which showed an average of 7,500 calories, i. e., should have evaporated 13.37 pounds of water theoretically, evaporated 8.17 practically (from and at the boiling point) and the heat was supposed to be distributed as follows:

	per cent.
Heat used in steam making	61.00
Ungenerated in combustible gases lost	5.5
Lost in hot clinkers and ash	1.5
Lost in hot products of combustion	5.5
Lost in smoke	0.5
Lost in evaporation of moisture	2.5
Lost in brick work	25.5
	100.00

We notice that the tests quoted by Mr. Willcox give similar results for the Michigan Coals, from seven to nine pounds actually evaporated, or from and at 212°F. from 9 to 12 pounds. And Mr. E. C. Fisher's test given below (p. 67) gives about 7 pounds actually evaporated, i. e., 8.63 lbs. per pound of combustible, or 59% of that given by Pennock's Calorimeter test, showing that the boiler was doing good work. The commercial evaporation is by convention fixed as the evaporation from a feed water temperature of 100°F. to steam of 70 lbs. gauge pressure. In Plate II we have the various methods of expressing heating power arranged in scale side by side, so that equivalent expressions may be seen at a glance. The commonest methods of expressing heating power are in units of evaporation, i. e., pounds of water changed to steam at a temperature of 212°F., or British Thermal Units, i. e., pounds of water raised one degree Fahrenheit. The tests of Mr. Edmond A. Edgerton, superintendent of the electric light and water works, Lansing, run 5½ to 9 pounds evaporated. We must remember that to fully estimate the heat obtained from coal we must know how warm the feed water was and how many degrees it had to be raised to the boiling point. Again, the boiling point is not always 212°F., though it is popularly supposed to be so, but it is higher as the steam and atmospheric pressure increases. Finally, if the steam is superheated or contains moisture, there is more heat used there. There are, therefore, a number of corrections to be applied before results in different boilers under different conditions are applicable. For instance the coal that would evaporate 30 pounds of water per hour (one commercial horse power), the temperature of the water being 100°F. and the steam pressure being 70 pounds, would evaporate 34½ pounds of boiling water under atmospheric pressure into steam of the same pressure. Even then conditions that cannot be exactly figured out, the different adaptability of different grates and draughts to different coals, and subsequent varying loss in smoke and chimney gases, in brick work, clinker and half consumed ash, and the different experience of different firemen in handling different coals are so important that results must be taken with caution, and are mainly used in showing what coal gives best results with a given boiler outfit. For this purpose they are very valuable and should be widely used. If one coal is 10 per cent more efficient than another, it means more than 10 per cent discount in price.

The conduct of a complete boiler test is the work of a mechanical engineer, and is surrounded by a multitude of minute precautions detailed in papers in the Transactions of the Mechanical Engineers referred to, which cannot be repeated here.

The following report of a trial by E. C. Fisher of the comparative value of Saginaw and Hocking Valley coal is a good illustration of a boiler test. It will be noticed that the Saginaw coal used appears to be a trifle less efficient than the Hocking Valley pound for pound, but considerably more efficient at the prices quoted.

TEST BY E. C. FISHER, ON ONE WICKES' PATENT WATER TUBE SAFETY STEAM BOILER.

Fuel—			
Kind of coal		Saginaw.	Hocking Valley.
Total amount consumed	Lbs.	6092.0	5808.5
Moisture in coal	%	5.5	5.
Dry coal consumed	Lbs.	5757.0	5518.08
	%	4.2	6.1
Total refuse	Lbs.	245.5	338.5
Total combustible	Lbs.	5511.5	5179.5
Dry coal consumed per hour	Lbs.	575.7	551.808
Combustible consumed per hour	Lbs.	551.15	517.95
Results of Calorimetric Tests—			
Quality of steam		.9925	.9927
Percentage of moisture	%	.75	.73

BOILER TEST—*Continued.*

		Saginaw.	Hocking Valley.
Economic Evaporation—			
Water actually evaporated per lb. Dry coal	Lbs.	6.93	6.99
Water evaporated per lb. dry coal from and at 212° Fahr	Lbs.	8.26	8.32
Water evaporated per lb. combustible from and at 212° Fahr	Lbs.	8.63	8.87
Rate of Combustion—			
Dry coal burned per sq. ft. grate per hour	Lbs.	25.5	24.5
Dry coal burned per sq, ft. water heating surface per hour	Lbs.	.363	.34
Rate of Evaporation—			
Water evaporated from and at 212° per sq. ft. grate surface per hour	Lbs.	211.04	204.1
Water evaporated from and at 212° per sq. ft. water-heating surface	Lbs.	3.00	2.90
Commercial Horse-Power—			
On basis of 34.5 lbs. water evaporated per hour from and at 212° Fahr	H. P.	137.9	133.2
Builder's rating	H. P.	144.0	144.0
Cost in coal to evaporate 100 lbs. of water from and at 212° Fahr	Cts.	14 4-10	15 8-10
Cost of coal per ton (2000 lbs.)	$ & Cts.	2.25	2.50
Water evaporated from and at 212° per pound wet coal	Lbs.	7.80	7.91
Efficiency of boiler	%	71.10	

The following blanks, used by Prof. Weil of the Mechanical Department of the Agricultural College, show the numerous items which should be noted in an accurate test. The Committee of the American Society of Mechanical Engineers give two forms for a standard test of boilers, the longer including 88 items, the shorter 33:

Description of Boilers for trial at..
of (No. and type)..
Date..
(a) Type of Boiler..
(b) Diameter of shell..
(c) Length of shell..
(d) Number of tubes. { Vertical..
Horizontal..
(e) Diameter of tubes..
(f) Length of tubes. { Vertical..
Horizontal..
(g) Diameter of steam drum ....
(h) Length of furnace..
(i) Width of furnace..
(j) Kind of grate bars..
(k) Width of air spaces..
(l) Ratio of area of grate to area of air spaces..
(m) Area of chimney..
(n) Height of chimney above grate..
(o) Length of flues connecting to chimney..
(p) Area of flues connecting to chimney..

Governing Proportions.

(a') Grate surface..
(b') Heating surface. { Water..
Steam..
Total..
(c') Area of draught through or between tubes..
(d') Ratio of grate to heating surface..
(e') Ratio of least draught area to grate..
(f') Ratio of least draught area to total heating surface..
(g') Water space (cu. ft.)..
(h') Steam space (cu. ft.)..
(i') Ratio grate to water space..
(j') Ratio grate to steam space..
3. Grate surface, wide................long................area..
4. Water heating surface..
5. Superheating surface..

6. Ratio of water heating surface to grate surface..

NOTE.—Items correspond to A. S. M. E. Standard Report of Boiler Trials.

Results of the Trial of (No. and type)..

Boilers at ....
To Determine ....
1. Date of trial ....
2. Duration of trial ....

Average Pressures.

7. Steam pressure in boiler by gauge...
8. Absolute steam pressure ....
9. Atmospheric pressure per barometer ....
10. Force of draught in inches of water...

Average Temperatures. Fahr.

11. Temperature of external air ....
12. Temperature of fire room...
13. Temperature of steam ....
14. Temperature of escaping gases ....
15. Temperature of feed water ....

Fuel.

16. Total amount coal consumed (includes wood x 0.4).....................................
17. Moisture in coal ....
18. Dry coal consumed ....
19. Total refuse dry....................pounds,==...
20. Total combustible (item 18 less item 19)................ ....
21. Dry coal consumed per hour..
22. Combustible consumed per hour ....

Results of Calorimetric Tests.

23. Quality of steam (dry steam taken as unity)...
24. Percentage of moisture in steam ....
25. Number of degrees superheated ....

Water.

26. Total weight of water pumped into boiler and apparently evaporated.............
27. Water actually evaporated corrected for quality of steam...........................
28. Equivalent water evaporated into dry steam from and at 212° F...................
29. Equivalent total heat derived from fuel in British thermal units...................
30. Equivalent water evaporated into dry steam from and at 212° F. per hour........

Economic Evaporation.

31. Water actually evap., per pound of dry coal from actual pressure and temp. ....
32. Equivalent water evaporated per pound of dry coal from and at 212° F............
33. Equivalent water evaporated per pound of combustible from and at 212° F........

Commercial Evaporation.

34. Equivalent water evaporated per pound of dry coal with one-sixth refuse at 70 pounds gauge pressure from temperature of 100° F. (==item 33 x 0.7249)......

Special.

35. Dry coal actually burned per sq. ft. of grate surface per hour....................
39. Water evap. from and at 212° F. per sq. ft. of heating surface per hour..........

Commercial Horse Power.

43. On a basis of 30 lbs. water per hour evaporated from a temp. of 100° F. into steam of 70 pounds gauge (==34½ lbs. from and at 212° F..................
44. Horse-power, Builders rating at................square feet per H. P.................
45. Per cent developed above or below rating...

NOTE.—Items correspond to A. S. M. E. Standard Report of Boiler Trials.

Very much less elaborate and yet quite instructive, in a comparative way, are the tests conducted by Mr. Edgerton, superintendent of the electric light and water works, Lansing, given below. In these tests a 12 hour run was made of each coal, and an attempt was made to leave the grates in the same condition as they were found.* The amount of feed water was measured and the feed water kept at a constant temperature of 110°F. The boiler pressure is nearly constant, about 95 pounds to the square inch, and the coal and ashes weighed as shown. Of course there are many chances for inaccuracy. The boiler pressure was not absolutely constant; the variations of atmospheric pressure and the temperature of escaping gases and the dryness of the steam was not noted nor the coal which preceded on the grate, and this might make quite a difference. Most of the above factors, however, would make no material difference in comparative tests. And if we reduce for some of them the water actually evaporated to units of evaporation, i. e., that which would be evaporated from and at 212°F. we find somewhere near the following values:

	U. E. 1st Series.	U. E. 2nd Series.	U. E. 3rd Series.
Average of Hocking Valley coals	7.38	8.32	…………
Saginaw	7.23	…………	7.32
St. Charles	…………	8.16	7.41
Corunna	6.49	…………	…………
Williamston	6.51 6.94	…………	…………
Bay City (Upper Verne)	…………	…………	7.56
Bay City (Lower Verne)	…………	…………	6.75

While the figures of Mr. Edgerton for the heating value of the Saginaw and Hocking Valley coals are much less than those given by Fisher, the relative values agree almost to a per cent. (8.32÷8.26=1.01 and 7.38÷7.23=1.02.)

The first set of tests were in 1898. Another set of tests preliminary to awarding the contract in 1899 were made up to June 11, 1899. In this two of the St. Charles coals were represented, the J. H. Somers Coal Company and the Michigan Coal Company. The average result (7.05 pounds actually evaporated=8.15 pounds from and at 212°F.), is just a little less than that of the two Hocking Valley coals (7.197=8.32 pounds from and at 212°F.), but practically identical with that found for the Saginaw Coal Company by Mr. Fisher.

In a third series from June, 1900, to February, 1901, the best result was about as before and the Somers Coal Company gave about the same result with the Saginaw on the first test, and in

---

*This is known as the "Alternate method" and seems to be growing in favor compared with the old "Standard method" of starting a new fire for each test.

the same general proportion with other coals as No. 3 and No. 4 of the second series. The coal from the Michigan Coal and Mining Company is from the upper seam and not that analyzed as A10, which does not represent what they ship. This latter was first worked and was analyzed by H. J. Williams. The sample tested at Lansing is probably better represented by Analysis J3.

It is not safe closely to compare the series, as there is probably some difference in the plant which makes one set not comparable with the other. Though the results on the Pocahontas (9.312÷9.229) and Wellston (7.622÷7.596) check quite closely, the Hocking Valley coals ran much better the second year.

LANSING WATER-WORKS TEST—FIRST SERIES.

	A.	B.	C.	D.	E.	F.	G.	H.
1.	Cedar Grove.......	Steam lump	8471	804	62581	7.387	$2.45	6030
2.	Goshen Hill........	Run of mine	10162	995	71433	7.030	2.25	6248
3.	Black Diamond....	“ “ “	11106	1293	70875	6.381	2.26	5647
4.	Massillon...........	“ “ “	10407	808	72547	6.971	2.33	5932
5.	Hocking Lump.....	“ “ “	11163	949	74400	6.634	2.35	5646
6.	New River..........	“ “ “	18765	524	68471	7.852	3.20	4907
7.	Hocking Valley*...	“ “ “	10706	808	71618	6.689	2 31	5791
8.	Cedar Grove.......	“ “ “	10000	1048	65614	6.561	2.35	5583
9.	Hocking Valley*...	Pea	12845	1558	75332	5.864	1.94	6046
10.	Mingo................	Run of mine	9669	682	71486	7.393	2.80	5281
11.	Jackson Hill*	“ “ “	10397	513	71185	6.846	2.50	5477
12.	Riverside*..........	“ “ “	9062	491	74280	8.196	2.60	6304
13.	Hocking Valley*...	“ “ “	11645	1021	74899	6.432	2.34	5497
14.	*Saginaw*............	“ “ “	*10754*	*895*	*67471*	*6.274*	*2.20*	*5703*
15.	*Corunna*............	“ “ “	*15551*	*1440*	*59520*	*5.633*	*2.25*	*5006*
16.	South Side.........	“ “ “	7896	565	63076	7.988	2 50	6390
17.	Wellston Shaft....	“ “ “	8405	120	64066	7.622	2.25	6775
18.	Pocahontas*.......	“ “ “	7089	285	65428	9.229	3.00	6153
19.	Not known.........	“ “ “	10073	1097	65862	6.538	2.09	6317
20.	*Williamston*........	“ “ “ {	*11178*		*62335*	*5.659*	*2.40*	
			10391	*440*	*62015*	*6.021*		

A. Name of coal.
B. Grade of coal.
C. Pounds of coal burned during the test.
D. Pounds of ashes.
E. Pounds of water evaporated during the test; feed water temperature, 110° F.=61.89 lbs. per cubic foot.
F. Pounds of water evaporated per pounds of coal.
G. Price of coal delivered in bins.
H. Pounds of water evaporated for $1.00.
Michigan coals are italicized.

1. Bidder, E. J. Corbett. No clinkers; light brown smoke.
2. “ Pittsburg & Wheeling Co. Light clinkers; smoke medium.
3. “ Black Diamond Co. Clinkers bad; heavy, dark smoke.
4. “ Pittsburg & Wheeling Co. Light clinkers; smoke medium.
5. “ O. W. Shipman. No clinkers; light smoke.
6. “ John Dailey. No clinkers; light brown smoke.
7. “ “ “ No clinkers; smoke medium. Compare Wilcox's test.
8. “ E. J. Corbett. Clinkers and smoke medium.
9. “ Ohio Central Fuel Co. Clinkers and smoke heavy.
10. “ E. J. Corbett. No clinkers; very little smoke.
11. “ John Dailey. No clinkers; heavy smoke. Compare Willcox's tests.
12. “ O. W. Shipman. No clinkers; very little smoke.
13. “ Ohio Central Fuel Co. Clinkers medium; smoke heavy.
14. “ Saginaw Coal Co. Clinkers and smoke medium. See other tests and analyses.
15. “ Corunna Coal Co. Clinkers and smoke bad; steam hard. See other tests and analyses.
16. “ V. R. Canfield. No clinkers; smoke medium.
17. “ Milton Coal Co. No clinkers; smoke medium.
18. “ V. R. Canfield. No clinkers; very little smoke. See 2nd series.
19. “ Wells & Clear. No clinkers; smoke heavy.

LANSING WATER-WORKS TEST—SECOND SERIES.

	Grades of Coal.	Lbs. of Coal burned during the test.	Lbs. of Ashes.	Per cent ashes.	Lbs. of water evaporated during the test. Temperature of feed water, 110 deg. 62 lbs. = 1 cub. ft.	Lbs. of water evaporated per lb. of Coal.
	B.	C.	D.		E.	F.
1.	Run of mine....	11789	1142	11.2	74648	6.332
2.	Run of mine....	8929	892	10.0	83142	9.312
3.	*Steam lump ....*	*11558*	*868*	*7.8*	*78616*	*6.802*
4.	*Steam lump.....*	*13150*	*1118*	*11.8*	*96552*	*7.311*
5.	Run of mine....	11500	1545	13.4	81034	7.046
6.	Run of mine....	10335	1092	10.6	79298	7.672
7.	Three-quarter lump.........	10532	945	9.0	78132	7.432
8.	Run of mine....	10305	500	4.85	78306	7.596
9.	Steam lump....	10110	905	9.0	70494	6.972
10.	Run of mine....	9825	885	9.0	75392	7.673
11.	Run of mine....	9340	740	7.9	69750	7.470
12.	Run of mine....	8608	670	7.8	69006	8.019

1. Montana Coal & Coke Co. Clinkers; not satisfactory to burn.
2. Castner, Curran & Bullitt, Pocahontas. No smoke or clinkers.
3. Michigan Coal Co., St. Charles, Black Pearl. Very light clinkers; heavy smoke. See tests, p. ——
4. J. H. Somers Coal Co., St. Charles. Light clinkers; heavy smoke. See tests, p. ——
5. W. H. Vance & Co., Kelley's Creek. No clinkers; heavy smoke.
6. M. A. Hanna & Co., Youghiogheny. No clinkers; smoke medium.
7. The Pittsburg Coal Co., Hocking. No clinkers; good burning coal.
8. The Milton Coal Co., Wellston shaft. Light clinkers; smoke medium.
9. Lowery Coal Co., Hocking, Congo. Clinkers and smoke badly.
10. Lowery Coal Co., Boomer, W. Va. No clinkers; light smoke.
11. The O. W. Shipman Co., Peerless, Cedar Grove. Very light clinkers; smoke medium.
12. W. H. Vance & Co., Massillon. No clinkers; light smoke.

LANSING WATER-WORKS—THIRD SERIES.—1900-1901.

	Date of Test. 1900.	Coal burned during Test.	Ash.	Per cent of ash.	Lbs. of water at 62 lbs. per 1 cubic foot.	Water evaporated with 1 lb. of coal.	Water evaporated for $1.00
1.	June 8.........	10124	1041	10	58280	5.756	4343
2.	June 9.........	8895	730	8.2	65410	7.353	5656
3.	June 12.........	9640	1105	11	58590	6.077	4901
4.	June 13.........	9512	594	6.2	63116	6.635	4825
5.	June 14.........	8520	593	6.9	57350	6.731	5280
6.	*June 16.........*	*10110*	*895*	*8.8*	*64480*	*6.377*	*5081*
7.	*June 21.........*	*9770*	*785*	*8*	*62992*	*6.447*	*5137*
8.	*June 22.........*	*9350*	*595*	*6.4*	*59210*	*6.332*	*5389*
9.	*Nov. 11.........*	*14626*	*1255*	*8.6*	*95604*	*6.536*	*5335*
	1901.						
10.	Jan. 4.........	13033	1510	8.6	101982	7.820	6133
11.	*Feb. 8.........*	*15916*	*3180*	*19.9*	*93310*	*5.846*	*5314*
12.	Jan. 20.........	14890	1835	8.1	103168	6.928	5542
13.	Jan. 10.........	12970	1490	11.5	101122	7.796	5846

1. Sandy Creek.
2. Boomer R. M.
3. New Pittsburg R. M.
4. Milton Coal R. M.
5. Pittsburg and Wheeling.
6. *Somers' Coal Co.*, St. Charles.
7. *Somers' Coal Co.*, from different shaft, St. Charles.
8. *Pere Marquette Steam Lump* (No. 2 Shaft).
9. *Michigan Coal and Mining Co. Steam Lump* (upper seam).
10. Pittsburg Coal Co.
11. *Silver Mather Co.*, Bay City.
12. Pittsburg Coal Co. No. 8.
13. Pittsburg Coal Co. ¾ coal.

The object of the foregoing section is to show:

First, what the heating power of our Michigan coals is likely to be.

Second, the importance and elaborate character of a thorough boiler test which will show the efficiency not only of the coal, but of the boiler plant,—such a test should be made by a trained mechanical engineer.

Third, the importance in dollars and cents and comparatively simple character of a test which will show the relative efficiency of different coals with same plant.

§ 11. Heating power by calorimeter.

Slosson and Colburn have described and illustrated Mahler's Calorimeter quite fully in the Wyoming bulletin, previously cited, which may be obtained gratis on application. It has been improved by H. J. Williams, in many important details ensuring greater accuracy, yet without modifying the general principle. One of his is in use at Johns Hopkins University and one set of analyses, Nos. A1 to A11, were made on a similar instrument. He has also made one for the United States in testing explosives.

The Mahler Calorimeter was also used by Lord and Haas, and in the test with Pray's Analyses (I3 and I4) at Cornell University.

The Mahler Calorimeter, even unimproved, is by far the most accurate method of testing the heating capacity of the coal, but it is also the most expensive. The Michigan Agricultural College have recently bought a Parr Calorimeter which we illustrate below (Figures 7 and 8), which is quite effective and much less expensive, a description of which will serve to explain the general method of making tests with other calorimeters. The method of making a test with it is as follows:

One gram of coal is weighed out, having been first pulverized so as to pass through a 100 mesh sieve, and dried at 105° to 110°C. (220°-230°F.). This is put into the body of a steel cartridge, A of Fig. 7, D of Fig. 8. To it is added 16 to 18 grams of sodium peroxide (Na_2O_2). The stem of the cartridge, C of Fig. 7, is screwed on. The whole is shaken and the little turbine fans or vanes shown in Fig. 8 attached by spring clips to the outside. The whole cartridge is then balanced on a cone inside a can (A of Fig. 8) containing two litres of water, 3 to 4° colder than the room. In this can a thermometer T is placed. On the top of the cartridge stem which projects from the indurated fibre insulation (B C), which surrounds the can, a pulley wheel slips, by which the cartridge may be revolved 50 to 100 revolutions per minute, with any light motor.

The stirrer is set in motion by a cord around the pulley P, which runs to any light motor (Plate III) that will turn the cartridge some 50 to 100 revolutions a minute, and a water current is started down past the cartridge through E and up past the bulb of the thermometer T. After a short time the temperature registered by the

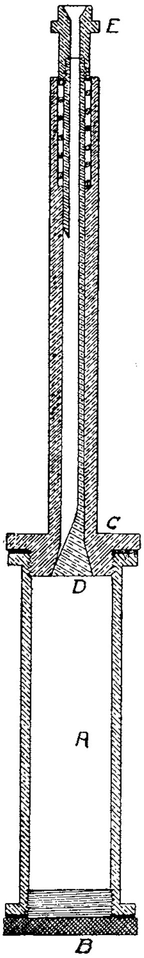


Fig. 7. Cross-section of cartridge for Parr Calorimeter.—See description in text.

thermometer remains so uniform that for a few minutes no change can be noticed, so perfect is the insulation afforded by the indurated fibre pails, B and C and the double lid with the air space between. Then down the stem E a piece of red hot copper wire one half inch long, is dropped. By pressing the top E of Fig. 7, which rests on a coiled spring the valve D is lowered so as to allow the wire to enter the chamber A, and start the combustion of the coal at the expense of the oxygen of the sodium peroxide. Heat is evolved and the mercury of the thermometer rises. In four or five minutes the highest point is reached, and the difference between the temperature before firing and after is, after subtracting

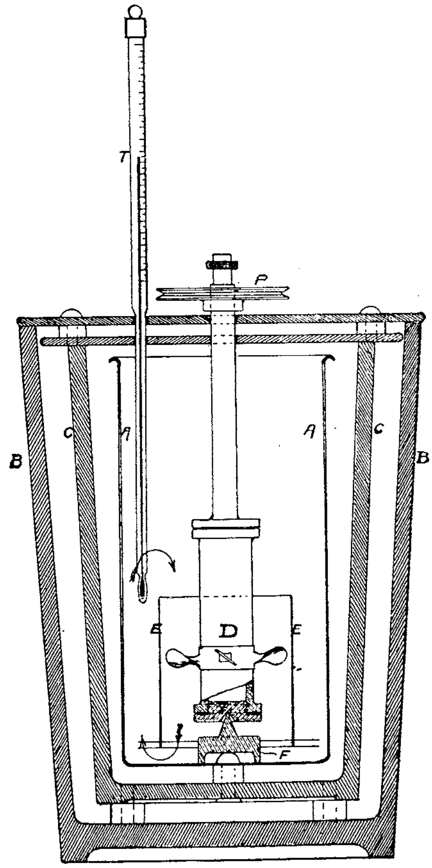


Fig. 8. Cross-section of Parr Calorimeter.—See description in text.

0.15°C. for the heat introduced by a piece of No. 12 copper wire one half inch long, in a fixed ratio to the heat in B. T. U. by burning a pound of coal. What this ratio is may ordinarily be best determined by a test on some standard substance, as there is some heat liberated by combination of the CO_2 and H_2O with the sodium oxide. For this purpose sugar charcoal or some other coal whose heating power has already been determined, may be used.

The factor given by the manufacturers is 3,100.

The novel idea embodied in the Parr Calorimeter is the introduction into the combustion chamber and intimate mixture with the coal of a chemical, Na_2O_2, which not only ensures complete combustion, but absorbs the gaseous products as fast as they are formed, so that enormous strength is not required to prevent their escaping, carrying heat with them. The test becomes rapid and inexpensive.

Now in the bomb calorimeter which is after all the standard, though much more expensive and difficult to manage, the general plan of operation is the same. But the coal is burned in an atmosphere of pure oxygen under pressure, and ignited by electricity. The gases of combustion are not allowed to escape, carrying the heat with them. In consequence the cartridge must be able to withstand an enormous bursting pressure. It is made spherical like a bomb. It has the advantage, however, that the question of the heat of absorption of the gases by the chemicals does not enter and that if need be, a fuel containing moisture can be accurately tested.

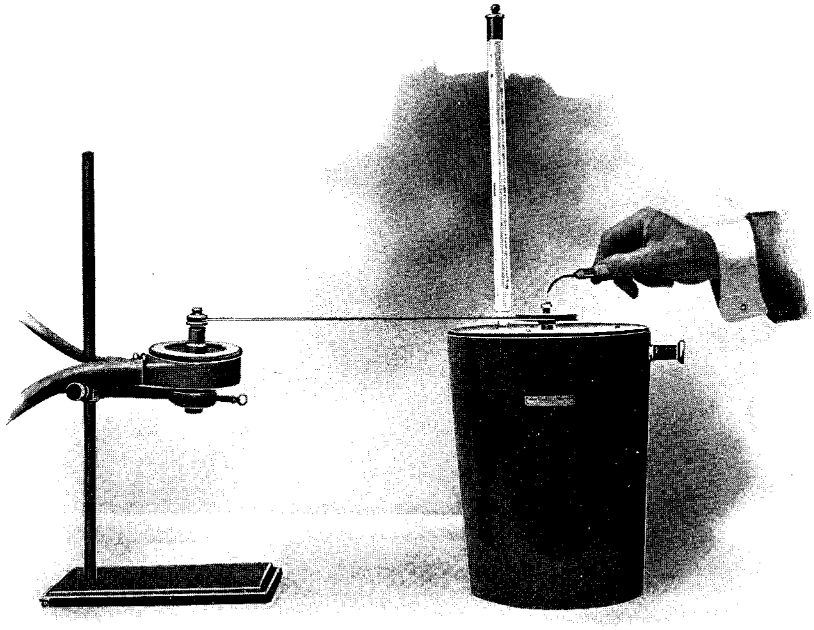
Another rather simple form of calorimeter, the Barrus, is figured in the report of the committee of the Mechanical Engineers on Standard Boiler Tests.*

Another modern form of calorimeter is the Carpenter Calorimeter. This was also used in Pray's analysis and by G. B. Willcox for his tests at the University of Michigan and is described in the proceedings of the American Society of Mechanical Engineers.†

The Thompson and other older forms of calorimeter will be found described in most text-books and are still used, but are much less accurate.

---

*Transactions 1899, No. 827 so many times referred to, also 1893, p. 816.
†Vol. XVI (June, 1895), No. 653.



THE PARR STANDARD CALORIMETER READY FOR IGNITION.

The determinations of the improved bomb calorimeter are the most accurate possible and are the standards by which every other test of heating power should be judged. Certain cautions must be given, however. As we have said it is not easy to get identical samples twice, and samples change slightly in keeping, the more finely they are ground.

Moreover, in practical work we shall never be able to reach the perfection of heat saving reached by the calorimeter. The degree to which we do this may be taken as measure of the goodness of the boiler arrangements, and as we have seen unless one is getting nearly 60% of the theoretical capacity, there is room probably for improvement in his boiler practice. Inasmuch as the calorimeter tests used to be expensive to make ($25) and required the use of an expensive apparatus not readily accessible, other methods to obtain the theoretical heating power have been widely used.

The following are the results of a series of tests for which we are indebted to G. B. Willcox, at the University of Michigan, with the Carpenter Calorimeter, published in part in the Michigan Miner, March 1.

The agreement with Williams' results is fair for Pocahontas coal, and for the St. Charles Black Pearl, compared with the St. Charles J. H. Somers No. 1. He gets considerably more out of the Pere Marquette and Saginaw than would be expected, unless they had lost quite a little moisture.

The object of introducing the series 12 to 23 is to show the variation of heating power with per cent of ash. Compare the Rifle River and Alpena analyses G4, 5, 7 and 8.* We see from the tests of Mr. Willcox that the heating power decreases in more than the ratio of the ash. Most of the material is from black shales or bone coal. No. 23 is, however, a genuine coal, perhaps from the Lower Verne.

---

*Also D11, I11, J5 and 6, pp. 113 to 118.

TABLE—CALORIMETER TESTS OF G. B. WILLCOX.

No.		B. T. U.	Per cent Ash.
1.	Riverside	15,104	5.1
2.	Pocahontas	14,579	4.0
3.	Jackson Hill	14,195	7.45
4.	Jackson Hill, Big Drift	13,987	5.55
5.	Montana Lump	14,325	5.3
6.	Bellmore, W. Va.	13,850	5.4
7.	New River	13,763	7.25
8.	Massillon	12,105	8.1
9.	Hocking Drift	11,935	9.33
10.	Jackson, Mich	10,070	9.1
11.	Jackson Hill	14,500	3.9
12.	Tests of exploratory drillings near West Bay City	8,884	37.8
13.		8,663	40.6
14.		8,618	42.8
15.		8,374	42.8
16.		7,967	42.7
17.		4,917	47.0
18.		5,133	47.7
19.		4,666	49.6
20.		9,125	23.
21.		9,633	23.
22.		6,866	36.
23.		12.500	9.5
24.	Saginaw Coal Co	13,000	3.25
25.	Pere Marquette	13,687	2.25
26.	Black Pearl, St. Charles	13,167	1.00

RIVERSIDE COAL. No. 1 of Table.

Mine located at Riverside, W. Va. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, '97. Observer, I. C. Woodward, '97 thesis. Tested at U. of M. laboratory.

Preparation of sample: Has been stored in a dry place for several years. Sample obtained by a system of quartering.

Quantitative analysis made by A. R. Miller, B. S. (Chem.) '97:

Per cent of water		1.52%
Per cent of volatile matter		38.5%
Per cent of fixed carbon (plus fixed sulphur)		55.07%
Per cent of ash		4.91%
Per cent of total sulphur		0.564%
B. T. U. in volatile matter	7,129	
B. T. U. in fixed carbon	7,975	
	15,104	

POCAHONTAS COAL. No. 2 of Table.

Mine located in Wise County, W. Va. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at the U. of M. laboratory.

Preparation of sample: Had been stored in a dry place for several years. Sample was obtained by a system of quartering.

Quantitative analysis made by A. R. Miller (B. S. Chem. '97):

Per cent of water		0.50%
Per cent of volatile matter		20.43%
Per cent of fixed carbon (plus fixed sulphur)		74.07%
Per cent of ash		4.98%
Per cent of total sulphur		0.605%
B. T. U. in volatile matter	3,849	
B. T. U. in fixed carbon	10,730	
	14,579	

See also test reported by R. C. Carpenter, Vol. XVI A. S. M. E.

JACKSON HILL COAL. No. 3 of Table.

Mine located at Jackson Hill, Ind. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at U. of M. laboratory.

Preparation of sample: Had been stored in a dry place for several years. Sample was obtained by a system of quartering.

JACKSON BIG DRIFT. No. 4 of Table.

Mine located at same point. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at U. of M. laboratory.

Preparation of sample: Had been stored in a dry place for several years. Sample was obtained by a system of quartering.

MONTANA LUMP COAL. No. 5 of Table.

Mine located at Fairmont, W. Va. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at U. of M. laboratory.

Preparation of sample: Had been stored in a dry place for several years. Sample was obtained by a system of quartering.

BELLMORE COAL. No. 6 of Table.

Mine located at Bellmore, W. Va. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at U. of M. laboratory.

Preparation of sample: Had been stored in a dry place for several years. Obtained by a system of quartering.

Quantitative analysis by A. R. Miller:

Per cent of water		1.50%
Per cent of volatile matter		35.52%
Per cent of fixed carbon (plus fixed sulphur)		58.%
Per cent of ash		4.98%
Per cent of total sulphur		.756%
B. T. U. in volatile matter	5,440	
B. T. U. in fixed carbon	8,410	
	13,850	

NEW RIVER COAL. No. 7 of Table.

Mine located at Fayette Co., W. Va. (Loup Creek). Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at U. of M. laboratory.

Preparation of sample: Had been stored in a dry place for several years. Sample was obtained by a system of quartering.

MASSILLON COAL. No. 8 of Table.

Mine located at Massillon, Ohio. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at U. of M. laboratory.

Preparation of sample: Had been stored in a dry place for several years. Sample obtained by a system of quartering.

Quantitative analysis by A. R. Miller (B. S. Chem. '97):

Per cent of water		1.7%
Per cent of volatile matter		40.48%
Per cent of fixed carbon (plus fixed sulphur)		51.2%
Per cent of ash		6.55%
Per cent of total sulphur		2.99%
B. T. U. in volatile matter	4,710	
B. T. U. in fixed carbon	7,395	
	12,105	

HOCKING DRIFT COAL. No. 9 of Table.

Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at the U. of M. laboratory.

Preparation of sample: Had been stored in a dry place for three months. Sample was obtained by a system of quartering.

JACKSON, MICHIGAN, COAL. No. 10 of Table.

Mine located four miles from Jackson, Michigan. Sample obtained from the University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, May, 1897. Observer, I. C. Woodward, '97 thesis. Tested at the U. of M. laboratory.

Preparation of sample: Had been stored in a dry place about three months. Sample obtained by a system of quartering.

JACKSON HILL COAL. No. 11 of Table.

Mine located at Jackson Hill, Ind. Sample obtained from University of Michigan laboratory. Tested by Carpenter Calorimeter. Date of test, November 1,

1898. Observer, G. B. Willcox. Tested at U. of M. laboratory. Temperature of room 75° F.

NOTE.—This coal is very clear and free burning; no smoke from discharge opening from calorimeter.

Nos. 12 to 23 are of drillings.

SAGINAW COAL COMPANY. No. 24 of Table.

May 20, 1899. Sample submitted by Robert M. Randall, manager. Sample consisted of about ten pounds of medium and small lumps packed in tight wooden box. Received by express.

General appearance: Burns clear and bright. Steady pressure in the combustion chamber. No smoke emitted. Combustion ceases suddenly without glow and leaves a light feathery white ash.

PERE MARQUETTE MINE. No. 25.

May 20, 1899. Sample submitted by Robert M. Randall, manager Saginaw Coal Company. Sample consisted of about ten pounds of medium and small pieces packed in a tight wooden box. Received by express.

General appearance: Burns clear and bright. Steady pressure in combustion chamber. No smoke emitted. Combustion ceases suddenly without glow and leaves a light colored ash without perceptible traces of fusible matter.

BLACK PEARL MINE. No. 26.

May 22, 1899. Owned by Northern Coal and Transportation Company, St. Charles, Michigan. Sample consists of a single lump picked up at the mine. No attempt was made to get a representative sample by quartering, but the lump selected was in general appearance an average sample.

General appearance: Burns clear and bright in the crucible. No smoke emitted from the combustion chamber. At the close of the test the glow is suddenly extinguished, and the ash shows no appreciable tendency to fuse. Ash is light and feathery.

The low per cent of ash in this select lump illustrates what we have said about the ash being in the finer stuff and slack.

§ 13. Heating power by reducing power. Berthier's method.

This method is an old one introduced by Berthier in 1833 and used somewhat by Prof. F. S. Kedzie. Recently Kerr, as above cited, has tried to improve upon it, but has made an error in theory which we shall endeavor to correct and at the same time derive formulæ easily simplified, yet sufficiently approximate for Michigan practice. Berthier's process is as follows:

Let the coal to be tested be intimately mixed with litharge PbO in the proportion of 20 to 40 (Berthier), or 50 (Kerr), of the litharge to one of coal and then placed in a crucible covered with a layer of PbO, and heated gradually. The coal will burn largely at the expense of the oxygen. Berthier assumed that all the combustible was carbon, but in reality we have, as Kerr remarks, hydrogen also, which gives out much more heat in proportion to the oxygen consumed. To see what the relation will be let:

x=amount of lead reduced by the weight of hydrogen h, changing to H_2O

y=amount of lead reduced by the weight of carbon c, changing to CO_2

z=amount of lead reduced by the weight of sulphur s, changing to SO_2

w=amount of lead reduced by the weight of iron f, changing to Fe_2O_3

$$x = \frac{206.9}{16} \cdot \frac{16}{2.02}\,h \text{ or } x = 102.42\,h$$

$$y = \frac{206.9}{16} \cdot \frac{32}{12}\,c \therefore y = 34.48\,c$$

$$z = \frac{206.9}{16} \cdot \frac{32}{32.06}\,s \therefore z = 12.93\,s$$

$$w = \frac{206.9}{16} \cdot \frac{48}{112}\,f \therefore w = 5.54\,f$$

$$z + w = 12.93\,s + 554\,(\tfrac{7}{8})\,s = 17.78\,s.$$

—if we assume, as Hilton's work shows that we may, that the sulphur and iron are combined in pyrite, so that we have $f=\frac{7}{8}s$. Assuming also, that heat of oxidation of the pyrite is 40 B. T. U. per unit of sulphur, of the carbon 14,600 B. T. U., and of the hydrogen 62,000 B. T. U. we shall have if P be the heating power per unit (gram) of fuel,

$$\begin{aligned} P &= 14{,}600\,c + 62{,}000\,h + 4{,}000\,s \\ &= \frac{14{,}600\,y}{34.48} + \frac{62{,}000\,x}{102.42} + \frac{4{,}000(z+w)}{17.78} \\ &= 423.4\,y + 605\,x + 225(z+w) \\ &= 423.4\,(x + y + z) + 181.6\,x - 198.5\,(z + w) \\ &= 423.4\,(x + y + z + w) + 18{,}638\,h - 3{,}530\,s. \end{aligned}$$

Now (x+y+z+w), the total amount of lead reduced in grams is determined by experiment and the result obtained by neglecting the other two terms is Berthier's formula for the heating value. But omission of these two terms introduces considerable error.

Kerr also neglects the term containing s or z+w which introduces no very large error. Since, for instance, in our Michigan coals the sulphur of the pyrite runs from 0.82 to 6.67% the error made by neglecting the term containing s will average 113 B. T. U. and will in no case exceed 256 B. T. U. The term containing h is more important, and may amount to over 1000 B. T. U.

Kerr attempts to allow for this term 18,638 h by adding $\frac{18{,}638\ h}{34.48}$ to the coefficient 423.4, and assuming a value for h according to the class of the coal, .02 for anthracite, .05 for bituminous coal. Thus, for our coals P = 450 (x+y+z+w = total lead reduced), by Kerr's formula. Of course if an ultimate analysis has been made we could determine h more exactly, but in that case the heating value can be as well computed by Dulong's formula.

But this correction of Kerr's will obviously be approximately correct, only when $x+y+z+w$, the total amount of lead produced per unit of fuel is nearly 34.48, that is to say when the fuel is pure carbon or the amount of ash present balances the amount of hydrogen so that the reduction of lead is the same as though it were all pure carbon. A glance at his table shows that this is not generally the case. Usually it will fall short and in such cases his estimates of the heating power are short,[*] unless the hydrogen is overestimated.[†]

For our Michigan coals we see that the hydrogen[‡] averages almost exactly .04 so that we may rewrite the formula.

$P = 423.4\ (\times \text{total lead produced}) + 623 + 18{,}638\ (h - .04) - 3{,}530\ (s - .0321).$

The last term we can compute if the coal has been analyzed for sulphur. It may run 100 units more or less. The hydrogen term ought not to vary more than a couple of hundred units. Comparisons seem to indicate that even with this formula the lead method gives too low results. There are errors in other ways. For instance a certain amount of oxygen will be derived from interstitial air. If we may judge from Kerr's tests on sugar charcoal it may correspond to 260 B. T. U. The PbO is liable to contain some Pb_3O_4 and the iron instead of being oxidized may be alloyed with the lead. On the whole I think that the lead results even with this formula must be taken as minimum.

§ 14. Heating power computed from ultimate analysis.

The heating power of a coal is often stated in B. T. U. not per pound of coal, but per pound of dry coal or per pound of combustible, i. e., coal free from ash and moisture, and occasionally (so by Lord and Haas) per pound of fuel, minus ash, moisture and sulphur. The more the above constituents are eliminated the more nearly constant the heating power is found to be. Now, if we have an ultimate analysis of the coal there is a formula known as Dulong's from which we can compute the heating power nearly as accu-

---

[*] For instance, in analysis No. 80 of his table I, if we assume 5% of hydrogen, a better estimate of the heating power would be about 12,900 instead of 11,915. It is easy to see that in his table II comparing oxygen and litharge methods, in treating pure sugar carbon or anthracite, his results will be in this respect nearly correct, while for bituminous slack, if my criticism is just, they may be, as indeed they appear to be about a thousand B. T. U. too low.

[†] For instance coals I9 and I10 which gave, with the Parr Calorimeter, 12,508 respectively, 13,438 B. T. U., reduced 27,397, respectively, 27.36 grams of lead per gram of coal used, i. e., 12,320 to 12,300 by Kerr's formula or by the one we have suggested, 12,223 B. T. U. the overestimate of the percentage of hydrogen compensating for the error in the formula.

[‡] Or rather the hydrogen effective in reduction ($H - \frac{1}{8} O$).

rately as it is determined by a calorimeter. It is written in two or three different forms which are substantially the same. Lord and Haas use it in this shape:

Heating power in calories $= 8080c + 34{,}462\ (h - \frac{1}{8}o) + 2250s$.

c, h, o and s being the amounts of carbon, hydrogen, oxygen and sulphur in one unit of coal. For 8080 some use 8140; for o, $o + n - 1$. If the C is burned to CO, not CO_2, 34,462 must be replaced by 29,000. Sometimes 600 or 1000w (where w = moisture) is subtracted, but this must not be done in comparing with a calorimeter of the bomb pattern, as the hot gases are not allowed to escape.

Heating power $= 14{,}544c + 62{,}031.6 + (h - \frac{1}{8}o) + 4{,}050s$, is the equivalent formula in B. T. U., but the boiler committee of the A. S. M. E. suggest the following form:

$$\text{Heating power in B. T. U.} = 146C + 620 \left\{H - \frac{O}{8}\right\} + 40\ S.$$

Kent in Mineral Industry, 1899, for 146c writes 146.5c.

In this formula the C, H, O, and S, are 100 times greater than c, h, o and s, being percentages instead of fractions of unity.

We have calculated and find that for Williams' analyses A1 to A11, at any rate, no closer agreement with the result of calorimeter experiment is made by attributing any effect to the moisture. As regards the use of $\frac{1}{8}O$ instead of $\frac{1}{8}$ (O+N—1), $\frac{1}{8}$ (N—1) is respectively .05, .04, .05, .06, .03, .02, so that its effect is trifling, not exceeding 40 B. T. U., which is much less than the errors due to analysis and sampling.

Using the A. S. M. E. formula therefore we have (computing by slide rule) the following table:

TABLE.—COMPARISON OF WILLIAMS' CALORIMETRIC TESTS AND DULONG'S FORMULA.

Analysis Number.	Heating units by Calorimeter.	Computed by Formula.	Differences.		$(H - \frac{1}{8}\ O)$
A. 1.	12,726	12,688	....	— 38	3.64
2.	12,868	12,876	+ 8	....	3.84
3.	12,836	12,506	....	— 330	3.32
4.	13,016	13,039	+ 23	....	3.81
5.	13,569	13,755	+ 186	....	4.72
6.	13,502	13,581	+ 79	....	4.66
7.	12,359	12,335	....	— 24	4.24
8.	12,861	12,702	....	— 159	4.17
9.	12,714	13,037	+ 323	....	4.62
10.	12,012	11,681	....	— 331	3.79
11.	12,099	12,035	....	— 64	3.99
			+ 619	— 946	

The errors in excess and deficiency are almost equally balanced in number, but both in number and size of errors the computed heating powers are a little below those actually found. Thus, it is obvious that substituting 145.44 for 146 or any lower coefficient for C and H or introducing the term $-\frac{1}{8}$ (N—1) would not improve the agreement. Nor would it help to add the oxygen absorbed by the ash when the iron changed to Fe_2O_3 to the oxygen. But to use Kent's value for the coefficient of C, to-wit: 146.5 would make a distinct improvement, for then the errors in excess and in defect would be practically equal.

It would help a little to assume that the iron in uniting with the oxygen gave out more heat than it absorbed in parting from the sulphur. But the discrepancies are not particularly in the S. No. A3, which is one of those most seriously out has but little sulphur, and the ultimate analysis shows nearly $\frac{1}{2}\%$ of hydrogen less than Nos. A1 and A2, while it has more volatile combustible. On the other hand the oxygen set down for A3 is considerably larger than any other analysis. As will be seen below, the results of computation from the proximate analysis check much better with the results of the calorimeter tests.

An error of less than 0.5% in the hydrogen would account for the discrepancy. Lord and Haas state the limit of possible error in an ultimate analysis as 0.5% in carbon and 0.2% in hydrogen.

In No. 9 also, where the greatest error occurs in the other direction the hydrogen is abnormally high and the oxygen low, and computation from the proximate analysis agrees quite well with the observed result. In No. 5, also, are the hydrogen and the computed value high, and in No. 10 the hydrogen low and the computed value low.

Unless these errors are due to errors in the determination of hydrogen, therefore, too much weight is given to the hydrogen.

If we plot the differences between computed and observed heating power referred to hydrogen, we shall find distinct indication that too much weight is given to the hydrogen. But taking the analyses of coals outside the state given for comparison we find no such indications, as we see from the following table:

	$H - \frac{1}{8} O$	Heating Power by Calorimeter.	Heating Power by Dulong For.		
C.1	3.41	12,885	12,630	....	— 255
C.2	— 4.04	13,867	13,565	....	— 302
C.3	— 4.49	14,572	14,514	....	— 58
C.4	— 4.22	14,880	14,748	....	— 132
C.5	3.12	11,674	11,413	....	— 261
C.6	3.71	13,151	13,267	+ 116	....
C.7	— 4.19	13,404	13,326	....	— 78

So that while we might add an empirical term to the Dulong formula and make the errors of more nearly even size, the improvement would hardly be sufficient ground for changing from the common formula, except Kent's change from 146 to 146.5, which gives a distinct but slight improvement.

§ 15. Heating power computed from proximate analysis.

Let us assume that we have determined volatile combustible v, fixed carbon f, sulphur s, and ash. We will assume as we found in testing the Dulong formula that the moisture and the ash have no effect. The fixed carbon we shall assume has the same effect as the carbon in the Dulong formula (though it really includes about ½ the volatile sulphur), and to begin we shall neglect the fact that this is determined too low when the ash contains much oxidized iron.* The remainder of the carbon is included in the volatile combustible. The table below shows how nearly fixed the proportion of carbon is in the volatile combustible. We subtract fixed carbon of proximate from total carbon of ultimate analyses of Table A and find ratio to volatile combustible:

TABLE.—PROPORTION OF C. IN VOLATILE COMBUSTIBLE.

Analyses	A 1	2	3	4	5	6	7	8	9	10	11
C	71.11	71.67	71.37	72.88	73.55	72.42	65.87	68.33	68.07	62.29	63.59
Fixed C	53.95	53.80	52.58	52.96	45.28	44.64	41.16	45.15	46.06	41.67	42.16
Diff	17.16	17 87	18.79	19.92	28.27	27.78	24.71	23.18	22.01	20.62	21.43
Vol. C	33.14	33.59	34.74	35.70	46.73	46.59	38 45	39.79	39.59	39.62	40.57
Ratio	.518	.530	.540	.557	.605	.595	.642	.582	.556	.520	.528
Average	.561	±.04	......	......	......	......	......	......	......	......	......

We see that the average is .561 ± .04

Thus, we may assign 146.5 × .561 = 82.2 ± 5.9 units to each per cent of volatile matter on the score of the carbon contained.

Next let us find the ratio of $(H - \frac{1}{8} O)$ to volatile combustible.

---

*As shown in table A, the error introduced by the S in the fixed carbon is insignificant.

The following table gives the ratio of $H-\frac{1}{8}(O+N-1)$ to volatile combustible for the first 11 analyses:

Analyses.	A 1	2	3	4	5	6	7	8	9	10	11
H...............	4.74	4.90	4.48	4.81	5.77	5.73	4.90	5.00	5.26	4.62	4.78
⅛ O............	1.10	1.06	1.16	1.00	1.05	1.07	0.66	0.83	.64	.85	.79
H − ⅛ O.......	3.64	3.84	3.32	3.81	4.72	4.66	4.24	4.17	4.62	3.77	3.99
N − 1..........	.40	.30	.40	.45	.50	.50	.01	.25	.49	.20	.19
⅛ (N − 1)......	.05	.04	.05	.06	.06	.06	.10	.03	.06	.03	.02
	3.59	3.80	3.27	3.75	4.66	4.60	4.24	4.12	4.56	3.74	3.97
Vol. matter...	33.14	33.59	34.74	35.70	46.73	46.59	38.45	39.79	39.59	40.57	39.62
Ratio Vol. m't'r	1.083	1.132	.0942	1.051	.0997	.0987	1.101	1.036	1.153	1.003	1.003

The average value of $H-\frac{1}{8}(O+N-1)$ is 4.03 or, including Dr. Koenig's analysis 4.00, of $H-\frac{1}{8}O$ is .04 more. The average value of the volatile matter is 39.00 and the ratio as we easily see is 0.104, just about one tenth of the volatile matter, so that we may also allow for each per cent of volatile matter 620×0.104=64.5 heat units on this account. Consequently we may in average assign 64.5×82.2=146.7 heat units to the volatile matter,—so nearly the same amount as the fixed carbon had that we may count it the same for both, say 146.6.

To the effect of the sulphur is hard to give theoretically even an approximate value. If there is oxygen added to the ash so as to make Fe_2O_3 out of the iron, and just enough iron is present to make FeS_2 then $\frac{3}{8}$ as much oxygen as sulphur is thus added to the ash, so that the chemist may estimate the carbon too low by that much.

We might accordingly allow and add for each per cent of S $\frac{3}{8}$ of 146 or 55 heat units on account of this deficiency in carbon. But on the other hand about half (the amount is not fixed) of the sulphur has been counted in the fixed carbon and allowed a heating value as though it were carbon. Accordingly $\frac{1}{2}$ (146—40) or 53 units should be subtracted on this account. Thus, as we see in Table A, the net result will be almost no change. One might suggest that inasmuch as the sulphur is included in the volatile combustible, in giving it any heating value apart therefrom, we were counting it twice and should deduct accordingly. But that is not true for the ratios to H and C of the volatile combustible were fixed, including the sulphur in the latter, and 146.7 heat units to each per cent of volatile matter is assigned on account of the H and C contained and not the S.

The Dulong formula assigns 40 heat units to the sulphur for its own combustion. It is not certain that the oxidation of the iron above mentioned really occurs completely. Ash is not infrequently magnetic. There may also be compensating loss of combined H from the clay, CO_2 from the calcite, etc. But on the whole we will take as an average formula for derivation of heating power from proximate analysis, if we use Kent's coefficient for the C,

Heating power = 146.6 (f+v)+40s.

Plate II, however, was computed for 146 times various values of (f+v). To the heating value in B. T. U. as derived by Plate II from the combustible therefore it will be well to add about 100 B. T. U. for a coal which appears low in sulphur, and 200 for one high in sulphur, in case the sulphur is not exactly determined, to get the best estimate of the heating power.

In the following table the results of computation by this formula are compared with the results of tests with Williams' Calorimeter.

TABLE.—COMPARISON OF COMPUTATION FROM PROXIMATE ANALYSIS WITH CALORIMETER TEST.

	A. 1.	A. 2.	A. 3.	A. 4.	A. 5.	A. 6.	A. 7.	A. 8.	A. 9.	A. 10.	A. 11.
Total Combustible f + v........	87.09	87.39	87.32	88.66	92.01	91.23	79.61	84.94	85.65	81.27	82.73
146.6 (f + v).......	12,778	12,822	12,812	12,997	13,487	13,374	11,644	12,452	12,536	11,914	12,128
40 s................	44	40	40	60	113	123	119	153	229	266	277
B.T.U. computed.	12.822	12,862	12,852	13,057	13,600	13,497	11,763	12,605	12,765	12,180	12,405
B. T. U., Test.....	12,726	12,868	12,836	13,016	13,569	13,502	12,359	12,861	12,714	12,012	12,099
	+ 96	− 6	+ 16	+ 41	+ 31	− 5	− 596	− 256	+ 51	+ 168	+ 306
Ratio of f : (f + v)	.618	.616	.602	.597	.492	.489	.518	.532	.538	.510	.519

General average of A. 1 to A. 11 is .516
Average of A. 1 to A. 3 is 0.612 ± 0.010, probably the Saginaw seam.
Average of A. 5 to A. 6 is 0.490 ± 0.002, Jackson coal, the Lower Verne.
Average of A. 7, A. 10 and 11, 0.515 ± 0.005, Lower Bay City, the Lower Verne.
Average of A. 8, A. 9, 0.535 ± 0.003, both Verne coals together.

We see that the agreement with the calorimeter tests is in general quite as good as that of the Dulong formula, and in but one case is the error greater.

The cases where it does not agree are all coals high in sulphur and ash, yet no higher than others for which it works well. I think that in such cases it is more difficult to get true average samples.

Kent has constructed a diagram[*] to show how the heating power varies with the proportion of fixed carbon in the combustible (f+v),

---

[*] Mineral Industry, 1892 and 1900.

it being greatest when the fixed carbon is 80% of the combustible, i. e., about 158.4 (f+v). It would be according to his formula 146.6 (f+v) when f was 59% of f+v. This is close to the ratio for the first three analyses above from the Saginaw seam, where also the heat of the sulphur does not make much difference. For these analyses, therefore, our formula, which may be considered as an empirical adaptation of Dulong's, is nearly accordant with Kent's. But for most of the remaining analyses, probably from the Verne seams, Kent's formula would give results far too low. However, Kent remarks that his formula does not apply well and gives too low results in the case of certain gas coals where the fixed carbon is less than 58%, such as these Verne coals are.

Lord and Haas proceed a little differently. From f+v they subtract s, i. e., find the combustible free from sulphur, as well as moisture and ash. Subtracting from the heating power of any coal that fairly attributable to the sulphur, and dividing the remainder by the combustible, ash, moisture and sulphur free, we find the heating power of the latter which they call H.

$$H = \frac{P - 40\,s}{f + v - s}$$

For Hocking Valley (Middle Kittanning) coal they find H=142.75 so that P=(H=142.75)×(f+v—s)+40s. See last row of table A.

We see, therefore, that their formula is very much of the same type as that we have derived independently from Dulong's formula, connecting the proximate and ultimate analysis of our Michigan coals, except that they have separated the sulphur entirely from the other combustible, which is theoretically correct, but practically inconvenient, and I doubt if there is any compensating increase in accuracy. At any rate no better agreement with the calorimeter tests appears to be obtained, and our formula can be applied more directly to the proximate analysis.

They have not allowed for increase in weight of the ash.

It is also to be remarked that the analyses of Williams upon which our formula is based (Table A) are exceptionally high in moisture and show more than is shown by other analyses of the same coals. Now it is quite likely that Kent's formula was based on compiled analyses in which the moisture was imperfectly separated from the volatile combustible, in which case we should expect that the volatile combustible would appear to have less heating power. For instance, in the gas tests at Pittsburg a sample of

Pere Marquette No. 2 coal (F8) was returned as having but 1.98% of moisture and 43.49% of volatile combustible. It is reasonably certain that the coal is essentially the same as the coals of analyses A1 and A3, and the moisture imperfectly driven off. Clay and pyrite retard the departure of the moisture. Lord and Haas' determinations of moisture were also made at a lower temperature, and their determinations are probably less.

Moreover, in view of the fact that crude petroleum has a heating power of about 10,500 calories or 18,900 B. T. U., it would seem quite likely that the volatile combustible matter, if carefully separated from the moisture, would have as high heating value as the fixed carbon, so that the supposition that it has less is very likely due to imperfect separation of moisture from it.

It is, of course, true that a large part of the difference in percentage of moisture is due to actual difference in the amount contained in the coals. The more finely divided it is the more moisture it seems to lose, the amount depending also upon the humidity of the atmosphere and the temperature and pressure. Prof. F. S. Kedzie finds that practically all the moisture is abstracted over sulphuric acid in vacuo, if the coal is finely powdered.

If we calculate the heating power of the sample analysis No. I1 the result will be 509 units in excess of the calorimeter result. If we apply it to Nos. I3 and I4, and assume one per cent of S, which is probably about right, we shall find the result nearly 1000 B. T. U. more than the calorimeter gave.

The calorimeter results of Nos. I3 and I4 are very low by any formula, or under any supposition, unless the heat carried off by the high percentage of moisture was not counted in. By comparison with analyses A1, I1, I2 and F8 on substantially the same coal we see how much the percentage of moisture varies, in the statements of different chemists.

§ 16. Analyses and samples described.

(A). *Analyses by H. J. Williams.*

All our work has been based upon the eleven analyses made for us by H. J. Williams. It should be said at once that these samples are not put forward to represent the coal as shipped* necessarily, though in most cases they are intended to be a fair sample of the coal as it occurs in the workable seam. They were not intended to replace commercial analyses, but to give some idea of the variety

---

*In which the sulphurous part may be removed or slate by carelessness enclosed.

of quality in Michigan coal, and if possible to serve as a basis by which one could from the proximate infer the ultimate analysis. This we have found that we can do in comparable analyses of the same set, but can in general only do with great caution, for different chemists seem to vary widely in drawing the line between moisture and volatile combustible, in these quite hygroscopic coals. Plate II gives a correlation of the different methods of expressing the heating power of coals, and also shows roughly what heating power may be expected from a given percentage of combustibles, or a given amount of lead reduced, in our Michigan coals, based upon Williams' analyses. Other analyses by other analysts all show less moisture relatively, but the heating power per unit of combustible comes out less, showing in all probability that the moisture was not so thoroughly separated in analysis, even if the coals had lost some moisture before analysis.

Analysis No. A1, from Pere Marquette Shaft No. 1, location, N. W. ¼ of section 32, Buena Vista township, T. 12 N., R. 5 E., about 300 paces S. and 700 paces E. of junction of Hess St. and Genesee avenue. The coal at the shaft rises in all directions, but rather rapidly to the east 14 feet or more and ceasing to have sufficient roof. A section of the seam is as follows from top to bottom:

Thin bedded poor coal ("bone coal")	7¾	inches.
Slate parting	1¼	"
Top of coal rather sulphury, not so much so in all places	4	"
Main coal seam from which sample of about 25 lbs. was taken about 50 yards south of the main shaft close to the south entry	32	"

A section of the strata near the shaft would be:

Clay	104	
Sand and gravel	3	107
Till (hardpan)	2	109
Good shale (slate) roof	19	128
Coal	3	131
Clay	1	132

The sample was taken by A. C. Lane April 15, 1899, reported June 26, reanalyzed by A. N. Clark (No. E1) about August, 1899, and again partially with iron determination about February, 1900, by C. H. Hilton (No. D1) with accordant results, and again later (reported August, 1900), by Reed and Bradley (H7 & 8). There has apparently been a gradual loss of about 4% moisture.

The Standard Mine (No. A2) is close by, though the coal is not continuous, being separated by a barren area, but the Saginaw

Mine is in the same continuous seam (analyses F3 and I1 to I8), the water draining down into it as it is 12 feet deeper.

Analysis No. A2. From the Standard Mine, Saginaw, in the N. E. ¼ of Sec. 6, Bridgeport township, T. 11 N., R. 5 E.

The coal is 147 feet below the surface at the main shaft.

The following is the section as shown by the recent air shaft, which is south of the main shaft (Part I, p. 33):

Sandy clay	90	
Fine grained blue clay	10	100
Impure "fire-clay"	3	103
Shale, dark	8	111
Conglomerate	4	115
Black shale	20	135
Coal, about	4	139
Fire-clay (fern leaves)	6	145

Where taken there is 4 inches of top coal with more ash, and below 44 inches of the main coal seam which was sampled.

Though this mine is not two miles from the Saginaw and Pere Marquette No. 1 shaft, it is separated from them, I am told, by a barren area. At this mine the shales have a fair flora, referred to in the letter of D. White.

According to H. J. Williams' report, June 26, 1899, the coal does not swell up or coke, but cinters together and forms a hard cake; reanalyzed with iron determination February, 1900, by C. H. Hilton (D2).

No. H2, by F. F. Bradley, is from the same mine, but a different sample. The ash agrees closely.

Do not confuse this with the Michigan Standard Coal at Sebewaing. This is apparently the same coal seam as No. 1, and the analyses there cited should be compared.

Analysis No. A3. This is an anlysis of about 25 lbs. of coal from the J. H. Somers Coal Co., Shaft No. 1, at St. Charles, Sec. 5, T. 10 N., R. 3 E. J. T. Phillips, superintendent; F. G. Benham, agent. The coal rolls so much that considerable sections are exposed in the fire-clay and roof. The total exposed section being:

	Feet.	Inches.
Blue clay	14	
Hard bed, carbonates of iron		1½
Blue shale	3	
Low grade "Cannel coal"		3
Main seam (as sampled)	2	11

On the south side of the mine is more of the so called cannel, on the north side, none. A section at the shaft is:

Clay	28	
Sand and clay	3	31
Hardpan	9	40
Quicksand	2.5	42.5
Black shale	25	67.5
Gray shale	16.5	84.0
Sandrock	19.	103.
Shale	0.5	103.5
Coal (the Lower Verne?)	2.	105.5
Fire-clay	6.	111.5
Gray shale	8.	119.5
Black shale	4.	123.5
Fire-clay	4.5	128.0*
Gray shale	23.	151.0
Black shale	2.5	153.5
Fire-clay	0.5	154.0*
Black shale	25.5	179.5
Coal (Saginaw Seam)	3.5	182

We notice that beside the coal worked there is another coal at 105 feet which is said to be sometimes 2½ feet thick, more sulphurous and of inferior quality, dipping 4 feet in the 18 feet of the breadth of the shaft.

Taken April 13, returned June 26, 1899. Upon being heated the above coals, A1, A2 and A3, do not swell up and coke but cinter together and form a hard cake. Reanalyzed with iron determination by C. H. Hilton, February, 1900 (D3).

It has also been tested by the Parr Calorimeter (February, 1901) with results of 12,586 to 12,741 B. T. U., or when dried 12,663 B. T. U. The moisture of the sample has diminished to 5.59%.

Analysis No. A4 (B4 & D4) is of a sample from the mine of the Owosso Coal and Mining Co., R. E. Travis, proprietor, taken May 31st, 1899. The present shaft is about 40 rods east and 150 rods north of the old shaft, which I visited in 1895, in the N. W. ¼ of the N. W. ¼ of section 23, T. 7 N., R. 3 E. The section is as follows:

	Feet.	Feet.
Clay	7 to 8	7
Sand and gravel	15	22
Sand rock	35	57
Slate (hard shale)	18	75
Coal	3	78

Under the coal in part of the mine is the clay, in part quite sandy. The shales contain nodules of carbonate of iron with sphalerite and pyrite, similar to those found at Grand Ledge and at the Standard Mine. For a description of this clay see Vol. VIII, Part I, page 27. Mr. Travis had mined in all directions from the shaft over 400 feet at the time of my visit, controls 300 acres, paid 5 cents to 8 cents royalty, and was getting $2.00 a ton for block coal, $1.60 for nut coal. The mine caters to what may be called a local and retail trade, but has recently been sold to the Twentieth Century Portland Cement Company. The coals dip sharply to the N. E. as is shown by the fact that at the old shaft the coal is at a depth of only about 40 feet. This shaft is now used as an air shaft and an escape shaft. There is a break at the end of the south drift or entry, and the rooms to the west of it rise rapidly. Much water under a strong head comes in here. A bore hole going 75 feet below the coal gives a large supply of water with a strong head. The axis of the trough runs N. W. and S. E. Though this mine is near Kincaid's, it is said to be separated from it by a sandstone bar. This and the difference in quality lead me to think that they may be different seams; this one the Upper Verne (compare A4 and I4), and the other the Lower Verne. The sample for analysis was taken from the east side, the section being as follows:

Black shale		10 inches.
Coal (perhaps upper inch belongs above)	2 feet	9 "
Sandy fire-clays.		

At the west end of the mine the section is somewhat as follows:

Shale with streaks of coal	8 inches.
Coal	32 "
Bone coal, "black jack"	7 "
Clay.	

There are fine *Stigmaria verrucosa*=*S. ficoides;* also Sigillaria and Lepidodendron at this mine, but no ferns were noticed.

From the nodules D. White has noticed *Cordaites robbii*(?), *Cardiocarpon ovale* Lx., *Cardiocarpon bicuspidatum,* Sternb. var. *ohioense* D. W. and *Mariopteris cf. inflata,* and infers a probable equivalence with the Upper Pottsville or Sewanee zone. At the old shaft the coal was dipping 8 to 10 inches in 2 yards, and there was a black shale (soapstone) roof full of impressions of reeds and pyrite. In the grey shale above it the zinc nodules occur. The section was:

Gravel or sand		16 to 26 feet.
Alternating grey shales and sandstones to		61 feet.
Black shale	2 to 3 ins.	61 feet 3 in.
Coal (2 to 4 feet)	2 ?	63 feet 3 in.
Fire-clay	12 feet.	

Analysis No. A5 (B5) is of a lump from the New Hope Coal Mine, Jackson, the main seam. No. A6 (B6) is of the top part, which I was told was somewhat different, but as we see, proves not essentially so. This mine is about two miles N. W. of the city limits on the S. W. part of section 21, T. 1 W., R. 2 S.

The mine, though in a small valley close to a county drain, is nevertheless upon a moraine about 80 feet above Jackson city. The section exposed in the mine is as follows:

Black shale	top.	
Top coal (analysis No. 6)	7½	inches.
Pyrite parting	½	"
Main coal (analysis No. 5)	32	"

There is considerable variety in the general section, and the coal lies in troughs which roll quite irregularly and more markedly southeastward, while to the N. W. it flattens out and becomes more regular, but the coal thins out and passes into black shale. Fifty feet west of the shaft the section is:

Surface	40′	
Slate	39′	79′
Coal	3′ 5″	82′ 5″

To the east the coal becomes more hard and sulphury and I think runs up against a normal fault which strikes N. N. W. There are said to be a number of cases in the Jackson field and one in this mine where reversed faults occur with a very flat hade, so that coal is shoved over the coal. The coal lies in a narrow trough not more than 150 yards wide, and several hundred long, so that when twenty years ago a hole struck coal here, other borings put down to test up failed to find it, and the project was then abandoned.

The output is about 60 tons a day, and as there is no railroad to the mine, the market is purely local, much being used in harvesting. The royalty was ten cents per ton on coal mined and sold. Screenings are not counted in computing royalty or wages.

The clay below the coal is soft for 4 or 5 inches, below that quite hard. A well is put down to 230 feet, mainly in white sandrock, with "soap rock" between that and the coal.

This is a coking gas coal (compare F7, G6, H4). I hardly think that Willcox's test No. 10, the exact location of which is not known, is of this coal.

Analysis No. A6 (B6) is of a lump from the top seam, which was supposed to be different. The high per cent of sulphur and low per cent of ash in this analysis made it seem probable that some of the sulphur was combined organically and not with the iron, as 3.07% S would imply 3.84% of Fe_2O_3 if the S all existed as FeS_2 and was all burned to Fe_2O_3. So I had it analyzed by Mr. A. N. Clark, and the iron especially determined, and though the ash is slightly more, the Fe_2O_3, as directly determined, would not yield enough iron to make FeS_2 with the S. It may be a question, however, in view of Hilton's results, whether there is not an analytical error, or more probably an irregularity in sampling. If the S and Fe are not determined from identically the same sample, the pyrite is so much heavier than the coal, that it is not difficult to get ½% difference. It is clear in any case that almost all of the S and ash of the analysis came from the pyrite.

Analysis No. A7 (B7 and D5) is from the Lower Verne, part of the Wenona coal seam,—not the best part, compare Analysis A12, and Plate IV.

This coal has also been analyzed by Dr. Koenig. His analysis is of both seams, and is rather better than ours. I took mine from the lower seam (Lower Verne) intentionally to see if there was any marked difference in comparison with his, especially in coking capacity. Mr. Williams reports a coke of small volume, well fused and of excellent quality. It is a true coking coal.

Analysis No. A8 (B8 and D6) is from the Verne (formerly Albee) Coal Co., N. W. ¼ of N. E. ¼ of Section 23, T. 10 N., R. 4 E. The coals here mined resemble the coals of the Wenona, Central and other Bay county mines, and I take them to be the same. In both cases there are two seams of coal close together, in both cases immediately associated with black shale containing marine fossils. It will be noticed also that in ratio of fixed carbon to combustible, this and the other analyses, A5 to A11, which I assign to these same seams, differ 10 points more or less from the Saginaw seams, but only 2% from the average, or are at extremes 5% from each other. Both coals are coking coals, but the lower is brighter and has less charcoal but more sulphur. The section is as follows:

	16′		
Putty clay	22′	38′	
Till hardpan	2′	40′	
Sand	25′	65′	
Shale	3¼′	68½′	
Coal at a depth of from 50 to 60 ft.			34″
Upper coal with much charcoal			7″
Slate			6″
Lower coal, brighter			
Fire-clay or shale below			

A well goes on to 75 feet and draws somewhat mineral water, while a well not far off has soft, not salty water at 107 feet.

Analysis No. A9 is of the Sebewaing coal, a large sample taken from the pile of the Michigan Standard Coal Mining Co. by Prof. H. Ries. They struck 4 feet 9 inches of coal at 92 feet depth and have from 7 to 17 feet of slate roof. Compare the records of numerous holes given in Vol. VII, Part II, in this neighborhood, and Figures 10 and 11 of that report, reproduced here as Figures 3 and 9. Analyses F1 and F6 are from other mines near by in the same seam, and agree in indicating considerable sulphur and a high percentage of gaseous matter.

Analysis No. A10 (B10 and D8) is taken from the mines of the Michigan Coal and Mining Co. (J. A. Etzold, Pres.), on the N. W. ¼ of the S. E. ¼ of Section 25, T. 14 N., R. 4 E. In this mine we have two coals, of which the lower was worked at the time of my visit (at present I understand the upper only is shipped), which was at an early date, Sept. 20, 1899, when the mine was only out 500 feet to E and not so far W. It is about 122 feet down through the lower coal. At the east end of the mine the two coals approach, and there is but three feet between them. The upper coal is more wet and gassy, but of better quality, apparently. See tests at Lansing Water Works in 1901, and also J3. A section is as follows:

Clay	72′	
Till	10′	82′
Shale	9′	91′
Extra hard ($FeCO_3$)	3′	94′
Slate and shale with Lingula shale	12′ 6″	106′ 6″
Upper Coal (Upper Verne)	2′ 6″	109′
Shale and Slate fossiliferous	9′ 7″	118′ 7″
Coal (Lower Verne)	3′ 9″	121′ 4″
Fire-clay	3″	122′ 7″

The shells found here are largely the same as found at the Verne Mine. See p. 42.

Analysis No. A11 (B11) is from the Central Coal and Mining Co. on S. E. ¼ of the S. E. ¼ of Section 25, T. 14 N., R. 4 E., i. e., joins the Michigan Mine just described so that one escape shaft serves for both. As the analysis shows, this is of the same quality as the Michigan lower seam. It is here also the lower seam, 125 to 130 feet down, the section being somewhat as follows:

Clay	78′		
Till	31′		109′
Shale	3′ 4″		112′ 4″
Coal	2′ 8″		115′
Sandrock (?)	11′		126′
Black shale	7′		133′
Bone coal	5″		133′ 5″
Coal	2′ 8″	3′ 6″	136′ 11″
White sandy fire-clay			

Analyses Nos. 7, 8, 9, 10 and 11 appear to be all from the same seam, the Lower Verne. As contrasted with the Saginaw seam, they are all high in ash, sulphur and volatile matter, but not coking coals, while the latter is low in ash, higher in moisture and not ordinarily, at least, coking. Analysis A12 is of the Upper Verne, in the Wenona Coal Mine, Bay County, and of better quality.

UPPER AND LOWER VERNE SEAMS, WENONA COAL MINE.

(B). *Analyses by H. J. Williams, referred to dry coal.*

Table B refers to the same analyses as Table A, but the percentages are all referred to dry coal, thus eliminating that uncertain element, the moisture.

(C). *Analyses for comparison by H. J. Williams.*

Table C gives the results of analyses and tests on a number of standard coals by H. J. Williams for comparison. The proximate analyses refer to the coal as it came, but the ultimate analyses and heating power tests refer to dry coal. In the case of the Pocahontas coal, however, C4, there is very little moisture anyway. This is perhaps the best standard coal to use for comparison. For instance, it is included in the Lansing Water Works and in Willcox's tests, and Willcox's Calorimeter results agree with Williams' to within 2%. While, according to the calorimeter tests the Michigan coals run from 80 to 90% of the heating power of the Pocahontas (p. 105), practically they yield about 65% to 75% as much, so much heat escaping up chimney in the evaporated moisture of the coal, etc.

C1. "Big Muddy" coal from Carterville, Williamson Co., Ill.

C2. Pittsburg coal. Average of four analyses and tests. Compare the analysis of Pittsburg coal by Wuth and Stafford, with which F8 is compared.

C3. Clearfield, Pa.

C4. "Pocahontas" coal,—A West Virginia Coal.

C5. Nut coal. Mount Olive, Macoupin Co., Ill.

C6. Kinkad, a Hocking Valley coal, average of two analyses.

C7. Yorkville, lump and fine.

It will be noticed that the best semi-bituminous coals give from 14,500 to 15,000 B. T. U., while the good bituminous run from 13,000 to 14,000 B. T. U. for dry coal. It follows by comparison that the heating power of the Saginaw seam is extra high when referred to dry coal, the weak point being the amount of hygroscopic moisture, for a bituminous coal.

(D). *Analyses by C. H. Hilton.*

Table D gives the results of analyses by C. H. Hilton, on material largely the same as Tables A and B. These analyses were performed as thesis work in the Michigan Agricultural College and published in the Michigan Miner for August, 1900.

Samples Nos. 1 to 4 were carefully taken from the material returned by H. J. Williams, with corresponding numbers. (D1 to

D4=A1 to A4, respectively.) Analyses D5 to D8 correspond to A7 to A10.

D9 is from Grand Ledge, about the same material, perhaps not so carefully subdivided as E3,—a lump from Jenkins' drift on Coal Creek almost beneath the pits, the shales of which are exploited by the Grand Ledge Sewer Pipe Co., Frank A. Taber, secretary. Quite a full description of this region was given by Rominger.*

The sewer pipe works are close to the N. E. corner of Section 10, T. 4 N., R. 2 W., and the material is mainly derived from a shale from a pit about a quarter of a mile N., close to the Spiritualist camp grounds, at the summit of a bluff overlooking Grand River and a small tributary. The section here exposed is:

3 ft. stripping of till.
4 ft. shale, gray, with nodules.
1 ft. black shale verging into coal.
2 ft. white clay, so called fire-clay. The lower boundary of this white shale undulates so as to indicate that this is merely the shale below altered.
4 ft. blue clay, with large nodules of siderite and some zinc blende, and traces of ferns.
1 ft. darker shale, the floor of the shale quarry. Passing to the east into the Boyle's Mine Coal (horizon of Upper Verne?).
20 ft. light and dark thin bedded sandy shales and sandstones, slaking up on weathering.
1½ ft. coal, which is the coal analyzed (Lower Verne?). White sandstone.

The analyses of the darker and lighter shales are given in Part I. South of the works there is also a pit which lies much lower, in the valley of a stream and filled with water, and as the dip of the beds appears to be a little to the north, if anything, it is probably stratigraphically lower. The section is:

15 feet cross-bedded sandstone.
2 feet coal, with black shale and Lingula mytiloides just above.
3 feet white shale which I am told is the layer which is sometimes used. It is of different quality from the other, and the pit is generally filled with water. The shale here is much richer in ferns. (See p. 44.)

The coal workings consist of a series of little adits or drifts very irregularly driven in the bluffs facing the Grand River and mainly on the south side about ten to fifteen feet above the stream. Next to the northernmost with thickest coal is Pratt's coal mine, the adit being about 300 feet in, and the coal 28 to 30 inches thick. The next worker south is Chas. Hodge, then Wilkinson, then two other little openings, then the Jenkins old drift under the clay pits, and there is a new shaft on the Spiritualist Camp Meeting Grounds, put down by F. Boyle to the upper seam.

D10 is from drillings of a thin seam of coal near Pinconning, S.

---

*Geological Survey of Michigan, Vol. VII, Part 1, p. 131.

E. ¼, Sec. 10, T. 17 N., R. 3 E., about 150 feet down, obtained through Mr. R. J. Mansfield.

D11 is from the Rifle River cannel coal, Sec. 3, T. 19 N., R. 4 E., about the same as G4 probably, though not identical samples. The coal is a cannel coal of very light specific weight, conchoidal fracture and little or no lamination, associated with Lingula shales, and showing no sulphur to the naked eye, so that the amount that the two analyses show is surprising. Upon exposure to air and moisture alternately, however, a white coating of iron sulphate soon forms. The section is quite fully described by Rominger,* as follows:

Disturbed material, drift	14	14
Hard calcareous sandrock	3	17
Black slate, with *Lingula mytiloides* and fish remains and cannel coal	10	27

There is also a lower seam (see analysis G5).

Mr. Hilton's notes on his work are as follows:

"It will be noticed that the moisture and volatile combustible matter are uniformly lower in my determination than in the original analyses by Williams. Inasmuch as the amounts of these two factors had little bearing upon the present investigation, I made the determination of them together. To get at as to where the loss came in I made moisture determinations on three samples and found the loss of moisture accounted for the loss in the total moisture and volatile matter. Without going further, I took it for granted that the loss was thus accounted for in every case. The loss in moisture necessitates a higher proportion in the constituents, and I find accordingly larger percentages of total sulphur and of ash. The amount of sulphur in the ash is very small and is considered as sulphate in the coal. The amounts of volatile sulphur agree quite closely in the two sets of analyses.

"So far as the investigation has been carried the determination of iron has been the significant feature. I would call attention to the peculiar relation the content of iron bears to the content of sulphur. One varies as does the other, and they stand in almost exactly the same relation to each other in every instance, viz., in combining proportion 56÷64.12 to form iron pyrite (FeS_2).

CONCLUSION.

"As we stated in the introduction, the work has not been carried to its farthest analysis; and whatever conclusions are drawn must be stated as strongly indicated and not as absolute or positively demonstrated. But there is a strong probability, amounting almost to a certainty, that the sulphur is all accounted for correctly.

"First, A small amount of sulphur is non-volatile, being found as sulphate with calcium. Gypsum is found in perceptible amounts in coal deposits and the non-volatile sulphur is thus easily accounted for.

"Second, That the volatile sulphur is all combined with iron in the form of iron pyrite (FeS_2).

"This second conclusion is given weight by the fact that in all the samples analyzed, all the sulphur and nearly all the iron are accounted for by combining them as FeS_2. It can easily be seen how, in one or two instances, these proportions would occur by accident and thus lead to erroneous conclusions. But it is extremely improbable that this accidental relation would occur in every case of samples of coal taken from eleven different mines in widely separated parts of the State. It seems just, therefore, to conclude that the volatile sulphur is rightly accounted for as FeS_2. This is not saying that the iron and sulphur were originally deposited in these proportions. But that does not concern this investigation. The present condition in the coal is what I am after."

I called Mr. Hilton's attention to the well known fact that bicarbonated waters containing gypsum will, in the presence of organic matter, yield H_2S freely. This would turn iron salts into sulphides.

---

*Vol. III, part I, pp. 141 and 142.

"One or two interesting observations may be added. The coals are to all appearances perfectly dry, yet when they are subjected to a temperature of 100°C for one-half hour they lose 5 to 10% of their weight. The coal beds all being in valley regions and surrounded by higher grounds, have been for ages subjected to a strong hydrostatic pressure, which may account for the large content of hygroscopic moisture. Even after being handled about and kept in a comparatively dry place for some time, these coals yet yield as high as 8% moisture."

METHODS OF ANALYSIS.

"*Sulphur.*—The method used for determining sulphur was a modification of Eschka's method and has been already described. (P.60.)

"*Ash.*—Ash was determined by burning off in the muffle ½ gr. of coal placed in a tared platinum dish, then weighing.

"*Iron.*—The ash from each determination for ash was thoroughly digested with strong hydrochloric acid, c. p. to dissolve out the iron. The HCl was then expelled with H_2SO_4. The solution of ferric sulphate was then run through a reductor and immediately titrated against a previously standardized solution of $KMnO_4$.

"*Moisture and Combustible Matter.*—I placed 1 gr. coal in tightly covered platinum crucible; heated over the Bunsen flame 3½ minutes, then over the blast lamp for another 3½ minutes. The loss is moisture and volatile matter. The determination of ash, moisture and volatile matter had little direct bearing upon the present subject. I made them to satisfy myself that the coal was practically of the same composition as it was in the original analyses. The samples had been handled considerably and it was thought there might be a loss of volatile matter accompanying a slight loss in moisture."

The origin of the investigation was as follows:

In looking over some of the analyses of Michigan coals made for me, for instance A6, it was noticeable how low the ash was compared with the sulphur, so low indeed that if we estimated that all the iron which was combined with sulphur in pyrite (FeS_2) remained in the ash oxidized into ferric oxide there must be some sulphur which was not combined with the iron. So I suggested to Mr. Hilton for a thesis to work over some samples which I gave him to see if this were really so by determining how much iron was really present. It should be explained that between analysis and re-analysis they had been some weeks in bags and boxes before being separated and put into smaller jars. The samples originally taken, largely by myself, weighed twenty-five pounds or more, and were divided after returned from Boston and analysis by H. J. Williams into lots of about a pound. Thus, though the usual pains were taken in dividing, the samples had considerable chance to lose moisture and organic gases, and might vary a little in quality in the division. On the whole the re-analysis agrees with the original analysis remarkably well and entitles both to a good degree of confidence. They indicate also the amount of variation which may be expected in analyses owing to variation in sampling and in the time between the taking of samples and their analysis.

It will be noticed that if Mr. Hilton had determined the moisture separately from the volatile matter throughout, he would have made complete proximate analyses, for by subtracting the amount of the ash and volatile matter from 100 we obtain the per cent of fixed carbon.

In regard to the relation of the ash and the iron, it may be noted that if all the iron were in the ash as Fe_2O_3, there would be 3-7ths more Fe_2O_3 in the ash than iron as given, and we see that in a number of cases the ash must have been practically all Fe_2O_3. But unless great and especial care is taken the iron will not be completely oxidized, but will appear in a metallic or magnetic shape. This, Mr. Geo. B. Willcox informs me, also has been his experience, and in such case of course the iron will not form so large a proportion of the ash.

The most important results of Mr. Hilton's investigation seem to me to be two. First, he has shown what a very small proportion of clay ash is in some of our Michigan coals. And in the second place, his results show that there is no sulphur in excess of that required to combine with the iron, but that they are almost in exact proportion, so that if we find the amount of iron in the coal and add one-seventh we shall find the amount of sulphur within a fraction of a per cent.

As it is far more easy to determine the amount of iron quickly and accurately than the amount of sulphur, this may be of practical value to the chemist. It suggests also that the sulphur was not there originally, but was precipitated by the iron, which was there first. The later statement is easy to receive and believe for bog iron deposits are common in connection with peat and muck deposits, and nodules of carbonate of iron are quite common in the coal measure shales. Now the waters of the coal measure shales are strongly bicarbonated, and beneath the coal measures are beds of gypsum, with which many of the coal measures are impregnated. It is a well known fact that if in bottling any carbonated waters containing gypsum any organic matter, such as a wisp of straw, should get in, H_2S is generated, a gas which would have power to convert the bog iron ore into iron sulphide.

It is also likely that iron sulphate has been reduced by the organic matter of the coal to iron sulphide. Finally, there seems to be a division into two groups of analyses; one low in sulphur, and another high, the percentages not being evenly distributed. This probably corresponds to the fact that the samples come from at least two distinct seams.

(E). *Analyses by A. N. Clark.*

The three analyses made by A. N. Clark, of the Michigan Agricultural College, in this table were also intended to throw some light on the same problem as Hilton's.

E1 is of the same sample as A1 and D1.

E2 is of the same coal as A6.

E3 is of the same coal as D9.

E1 and E2 would lead one to infer an excess of S over that required for sulphide of iron, but in view of the other analyses on the same samples, it appears likely that the results in sulphur are too high. This is probably due to the chemicals used in analysis not being free from sulphates. Mr. Hilton found the same difficulty in the beginning of his work,—the sodic carbonate supposed to be chemically pure, not proving such. The analyses otherwise agree quite well though made by different chemists, and the moral I would draw is the advisability of iron determinations as a check on the sulphur determinations.

(F). *Proximate Analyses.*

Table F includes a number of proximate analyses by various chemists. The accuracy of these we do not guarantee. As reported to me the sulphur is included in the summation to 100%, and in all probability to make room for it from the per cent of volatile combustible found as above described (p. 62), one-half of the per cent of sulphur found is subtracted, and the other half from the fixed carbon. Therefore, to make them more comparable with analyses of Table A, I have added what the original figures for the volatile combustible and fixed carbon probably were.

F1. Sebewaing coal, probably from the mines of the Saginaw Bay Coal Co., at 80 to 90 feet depth, on section 18 of Sebewaing, T. 15 N., R. 9 E.

E. Speidel analyst, Twelfth Annual Report of Saginaw Board of Trade,—also our reports, Vol. V, Part II, p. 84, and Vol. VII, Part II, p. 218.

The following is a typical record from the neighborhood (Vol. VII, Pt. II, p. 150):

Sand	3′			
Clay	39′		42′	
Hardpan	3′		45′	
Sandrock	26′	4″	71′	4″
Coal, about		5″	71′	9″
Sandrock	8′		79′	9″
Slate		6″	80′	3″
Sandrock	7′	1″	87′	4″
Coal (analyzed)	4′		91′	4″
Light shale		3″	91′	7″

While the following, being near by, shows the relation also to the underlying strata:

Pleistocene	Clay	51′			
	Sand and gravel	1′		52′	
Coal bearing series (Pottsville?)	Loose sandrock	2′		54′	
	Hard rock	2′		56′	
	Dark sandrock	18′		84′	
	Coal, about		6″	74′	6″
	Sandrock	1′	6″	76′	
	Slate	6′		82′	
	Coal (analyzed)	3′	8″	85′	8″
	Bottom slate	1′	4″	87′	
Parma (?)	Sandrock (Somewhat water bearing.)	13′		100′	
Grand Rapids	Light slate or sand fire-clay	96′		196′	
	Hard dark rock (dolomite)	24′		220′	
	Slate	20′		240′	
	Hard lime rock	8′		248′	
Napoleon (Upper Marshall.)	Sandrock	55′		3′ 30	

In analysis this coal resembles the Lower Verne, and the occasional presence of another coal not far above it is significant.

This and F6 have the high volatile combustible and sulphur of the Verne seams though the volatile combustible is almost *too* high, and the ash must be almost wholly iron oxide from the iron sulphide. The samples may have been select lumps. Analyses A9 is probably of the same coal, but was taken by H. Ries unselected from the pile at the tipple.

A section of the coal seam at one point in the Sebewaing Coal Co.'s mine was:

Bone coal (burns but retains its bulk after burning, heavy)	0′ 4″
Marcasite	0′ 1″
Main coal	5′ 0″

Mr. Chas. Holmes says: "Pyritic iron is distributed throughout the coal, reaching in quantity as high as 25% of the coal seam, and masses of it called boulders by the miners, in cubical crystals are found in the raw state. But while the amount of sulphur in the form of iron pyrite is undesirably high in this coal, which lessens its value by the formation of sulphide of iron and tenacious clinkers which have a tendency to destroy grate bars, still in furnaces where proper appliances have been used to overcome this objectionable feature, the coal has proved of high value for heating purposes."

F2. An old analysis of the Corunna coal from the Twelfth Annual Report, Saginaw Board of Trade. This is of the coal of the Corunna Coal Co., Tod Kincaid, manager, on Sec. 13, T. 7 N., R. 3 E., the same as F5 and G3. Inferior both in ash and sulphur to A4, which is near by at about the same depth.*

---

*I suspect that this is the Lower Verne coal from the analyses, and the fact given me by Mr. W. H. Hess that the roof is largely limestone, seems to be confirmatory.

F3. One of the first analyses of Saginaw coal, by A. W. H. Linders. It is cited with comparative boiler tests of Saginaw and Hocking Valley coal. Evidently the moisture had been driven off beforehand, and probably a little of the volatile combustible, and we cite it mainly to call attention to the fact that it is not an analysis of the natural coal.

F4. Analysis made by Heim Bros of Saginaw, for the Saginaw Clay Mf'g Co., is supposed to be of the coal which was mined incidental to their shale work at Flushing. S. W. ¼ of Sec. 22, T. 8 N., R. 5 E. A view and description of their quarry is given in Part I. The general type of this analysis is that of the Saginaw seam,—high in moisture and fixed carbon and low in volatile combustible and sulphur. Borings on Sec. 15 and elsewhere in the neighborhood, however, show that there are at least 216 feet of coal measures here and indicate a higher position for it.

Compare analyses J7, 8 and 9, of drillings near by.

F5 is of the Corunna Coal Co. coal, an analysis furnished by T. Kincaid. Compare F2 and G3. The exact seam from which these analyses come is not well known.

F6 is of the Saginaw Bay Coal Co., coal at Sebewaing, by W. H. Coffron. Compare F1.

F7 is an analysis of Jackson cannel, quoted by A. Winchell 1861. The large amount of volatile combustible is noteworthy and A5 and A6 are much like it, except that they have more water and less volatile combustible, and less sulphur. The former difference may be due to the analyst.

F8 is an analysis furnished by Wuth & Stafford in connection with the report cited above p. 64* on the availability of the Saginaw coal for a gas coal. Comparing this analysis with A1 to A3 the lower amount of moisture is noteworthy. This appears to be due to the imperfect separation of the moisture from the volatile combustible. The amount of S is also abnormally low.

(G). *Partial and proximate analyses of recent date.*

G1. By Prof. C. A. Davis, for O. W. Blodgett, of a coal from 89 to 110 feet down, supposed to be a pocket of drift coal, near Munger.

G2. Average of nine analyses by students under F. S. Kedzie, of a piece of drift coal from Scotts, Kalamazoo county.

G3. Corunna Coal Co., average of 13 analyses made by students of Prof. F. S. Kedzie at the Agricultural College.

---

*Also Michigan Miner, May, 1901, p. 17.

G4. Rifle River cannel coal, Analysts Dickman and MacKenzie, No. 8615. Through S. G. Higgins, Esq.

This is practically the same material of which D11 is an analysis, and the sulphur and ash check quite fairly. The material has a conchoidal fracture and a little lamination and occurs in association with Lingula shale. Near the river it is said to be but 17 feet down to this coal.

Beneath this cannel coal is said to be the seam of bituminous coal represented by G5.

I do not feel absolutely certain, but in all probability this analysis fairly represents the coal of the Eureka Coal Co., of which the following test by Geo. F. Sherwood of the Jackson Gas Works is given in the Saginaw Evening News of July 23, 1898:

Charge of coal	4,800 lbs.
Gas	15,600 cu. ft.

Burns freely with no clinkers, and makes a very hot fire.

G5. Rifle River coal, lower seam, a single lump, by T. C. Phillips, at the Agricultural College, for E. C. Sovereign.*

G6. Jackson coal, Rominger, agrees very well with A5 and A6 in showing that the coal at Jackson mines has over 40% of volatile combustible, and is a gas coal.

G7. Analysis of black shale from near Alpena, through W. H. Johnson, showing the real character of the stuff which often starts coal excitements. Analysis of the ash will be found in Part I of this volume.

G8. Is an analysis of the five feet of coal shown in the following record from Sec. 13, Bingham Township, Clinton county, T. 7 N., R. 2 W., by Prof. F. S. Kedzie for M. H. Kniffin.

Surface	103	103
Sandrock	7	110
Clay, some coal	2	112
Coal	5	117
Limestone	7	124
Coal	1½	125½

(H). *Analyses by Bradley and Reed.*

The analyses of this table were made by Mr. F. F. Bradley mainly; Nos. 1 to 6 at Alma, and with the assistance of Prof. C. A. Davis.

H1. Was reported as from the Verne mine, St. Charles. The

---

*This agrees quite fairly with older results (See Saginaw News July 19, 1898), less than .75 S., and 4¼% ash. A shaft is said to have gone down to this seam and found it 4½ feet thick and of good quality.

analysis is distinctly that of a St. Charles coal, the Saginaw seam, and not one of the Verne coals. Compare A3.

H2. From the Standard mine, Saginaw. Compare with A2.

H3. From the Valley coal mine (Dutch Creek coal) near Bay City, as I suppose from the Monitor seam.

H4. From the New Hope mine, northwest of Jackson, should be compared with A5 and A6, which it resembles in proportion of volatile and fixed combustible.

H5. From the Trumbull mine, is of a shaft worked only a short time, northwest of the old Woodville mine, five miles from Jackson, Sec. 24, T. 2 S., R. 2 W., and is only a partial analysis.

H6. From the Wenona mine, Bay City, agrees pretty well with G2, but not so well with A7.

This mine has the following sections:

Clay	74′	
Sandrock	9′	83′
Shale (see Part I of this Vol.)	37′	120′

Black shale, with *Lingula mytiloides*, which also occurs abundantly at the air shaft, is the base of this shale.

Coal, lineations well marked with much dull charcoal.	3′	6″ to 2 ft.
Parting of shale and sulphur streaks		10″
Coal (as sample) brighter, more pitchy in luster	3′ to 2′	
Fire-clay, very siliceous clay shale, passing into a fine grained sandstone		
The coal is at a depth of 130 to 140 feet and the two coals are shown in Plates IV and VIII. Compare analyses A7 and A12		

The lower bright coal I take to be the Lower Verne, while the upper dull coal may be the Upper Verne or Monitor coal.

Going east 1,300 feet a 10-inch coal comes in on top of the upper seam. Where first seen it is 3 to 4 feet above, separated by a white sandy clay and gradually getting down to within 10 inches of it.

Compare this with the section of coal reported at Handy Bros.' Mine:

Coal, rusty with a few inches FeS_2 at top	3′	6″
Parting, few inches.		
Coal, brighter, shinier, not as hard as upper coal, some FeS_2 at bottom	1′	6″
Parting		4″ to 11″
Coal	1′	

The bed rock is at 75 to 80 feet depth, the coal is at 110 to 120 feet or less, but there are 20 to 18 feet of roof shales.

H7 and H8. By F. F. Bradley and Reed of Chicago University, are from the same sample, taken from the Pere Marquette No. 1 shaft, as A1, B1, D1, E1. Analyses H7 and H8 are slightly better in most respects. The loss of moisture may be due to drying, possibly.

H9. By F. F. Bradley, is of the same sample as A9.

H10 and H11 are by Reed and F. F. Bradley, of the same sample as A10.

This suite of analyses do not agree satisfactorily with duplicates and suggest the question how much variation can be produced in reducing from the large sample taken to the small sample analyzed, and how much is due to difference in chemical manipulation.

The suite H runs steadily high in fixed carbon, yet if we compare A1 with A9 we find that H8 and H9 are similarly related, so that the relative behavior of the coals is the same.

(I). *Recent Analyses.*

Table I contains a number of recent and quite reliable proximate analyses, which are mainly accompanied by calorimetric tests.

I. This was an analysis by J. D. Pennock of a barrel of coal cut from the bottom to the top of the seam, at the mine of the Saginaw Coal Co. N. E. quarter of Section 31, Buena Vista township, T. 12 N., R. 5 E. It yielded 10,600 cu. ft. of gas, 110 lbs. of tar, 19.6 lbs. ammonia sulphate, and 54.50% of very good light coke, which analyzed:

Volatile matter	1.0
Fixed carbon	92.2
Ash	6.8
	100.0
Sulphur	.9

This was analyzed at the Solvay Co.'s works at Syracuse.

A record of the section at the mine is as follows:

Clay	54′			
Sand and gravel, which turned out in the shaft to be a diagonal streak of a few inches	3′		57′	
Clay	37′		94′	
Sand	4′		98′	
Hardpan to bedrock	5′		103′	
Slate	1′		104′	
Coal, Lower Verne?		1″	104′	1″
Gray slate	18′		122′	1″
Slate	6′	6″	128′	7″
Coal, Middle rider?		4″	128′	11″
Hard sandy clay	1′		129′	11″
Gray shale	5′		134′	11″
Strong black shale	12′	2″	147′	1″
Coal, this is the coal mined (Saginaw seam).	3′	3″	150′	4″
Fire-clay	18′		168′	4″
Sand rock	34′		202′	4″
Sandy shale	3′		205′	4″
Slate	16′		221′	4″

This is a little south and about 1,700 feet east of the north quarter post of Sec. 31, T. 12 N., R. 5 E.

This coal analyzes like the Pere Marquette, Somers, and other coals of the Saginaw seam and as such I take it. It rises rapidly to the Pere Marquette No. 1, and a little further east plays out against a big sandstone. The high per cent of moisture is characteristic, shown also in I3 and I4, and it is not superficially wet, but hygroscopic.

Analysis I2 was of a carload of slack with much sulphur and slate, which did not make a good coke—all came out in a fine slate. It was impossible to drive off the last traces of gas. The coal yielded very little bituminous matter, a small amount of tar (25.10 lbs. per ton), 59.15% of a soft useless coke, of sulphate of ammonia, 17.40 lbs. per ton, of gas 10,000 cubic feet. Analyzed by J. D. Pennock, Feb. 17, 1899.

Analysis of coke:

Moisture	3.2
Volatile matter	7.03
Fixed carbon	66.02
Ash	23.75
	100.00
S.	2.097

These analyses illustrate a general principle, that with the introduction of slate or bone coal represented by ash in the analysis, the fixed carbon drops faster than the volatile.

This analysis of slack is of course of no value as indicating the quality of the coal and there is more slate than usual in the marketed product. But it is very interesting, owing to the fact that less moisture appears than in the coal J1, or the coke. The idea suggests itself that the slate and the sulphur can hold back the moisture which would otherwise be given off by the coal.

I3 and I4 are duplicate analyses of a sample taken by T. Pray, of Boston, in December, 1899, from a car of Saginaw coal, and analyzed at Cornell University. The calorimeter results are obtained by Mahler and Carpenter Calorimeters (p. 52).

I5 and I6 are derived from I3 and I4 by computation for dry coal, and I7 and I8 similarly for combustible.

These analyses show the largest amount of moisture of any quoted, though they are nearly equaled by some of Williams', e. g., A1 and A2.

Mr. Pray says, however, that the moisture is not surface moisture or snow, but an essential part of the coal. This burned up freely but soon lost its heat.

I9 is of drillings and I10 is of a lump coal from the Robert

Gage Coal Co.'s shaft at St. Charles, on Section 10, T. 10 N., R. 3 E. I suppose the samples to be from the same seam as A3. The analyses were made at the M. A. C. laboratory, and the calorimeter tests made with the Parr Calorimeter. The same puzzling and important discrepancy in moisture to which we have already referred, appears.

I11 is of a lump from the top eight inches of "bone coal" from the same seam. It will be noticed that it has no more ash than A7, 10 and 11, H9 and J6, and that the ratio of fixed carbon to combustible is that of the main seam, I10.

I12 is of fragments of an upper coal, one of the Verne coals encountered in sinking the shaft of the St. Charles Coal Co.

(J). *Supplementary analyses.*

Table J contains some coal analyses 1 to 6, by Lathbury and Spackman, which we owe to Mr. U. R. Loranger. They are all from the neighborhood of Bay City and all probably from the Verne seams.

J3 is from the upper seam at the Michigan Coal and Mining Co.'s mine. Compare A10. It shows clearly how much better is the upper seam which they are now working, the upper Verne.

J4 is from the old Monitor mine, I take it, from the same seam.

The other samples are from undeveloped drillings, and the high percentage of ash is doubtless in part due to the admixture of slate.

J1 and J2, and J5 and J6 resemble in a general way A10 and A11, and are probably from the same seam. The ratio of fixed carbon to total combustible is lower than in the Saginaw seam.

J7, J8 and J9 are analyses by H. J. Williams of samples of drillings supposed to have come from near Flushing, which had been kept for quite a while, and are probably from two different seams.

(K). *Peat analyses by W. H. Allen.*

The analyses of this table are of peat, and were made by Prof. W. A. Allen of the Detroit College of Medicine for the Chelsea Compresso Peat Co., of Detroit and Chelsea, Mich. No sulphur is reported. It is generally absent in peat. The percentage of moisture, which has not been separately determined, would probably vary from 10% to 25%.

TABLE A.—ANALYSES BY H. J. WILLIAMS.

Number	1	2	3	4	5	6	7	8	9	10	11	12
Location	Pere Marquette, No. 1.	Standard, Saginaw.	No. 1. Somers, St. Charles.	Owosso.	New Hope, Jackson.	New Hope, Jackson.	Lower Verne, Bay Co.	Verne.	Sebewaing.	Michigan Lower Verne.	Central Lower Verne.	Upper Verne, Bay Co.
Sp. Gr.	1.269	1.260	1.285	1.27	1.247	1.244	1.32	1.32	1.34	1.33	1.36	....
Moisture	10.15	10.67	7.79	7.58	5.58	5.93	8.71	5.82	6.09	5.01	4.52	3.78
Volatile Comb.	33.14	33.59	34.74	35.70	46.73	46.59	38.45	39.79	39.54	39.62	40.57	41.18
Fixed Carbon	53.95	53.80	52.58	52.96	45.28	44.64	41.16	45.15	46.06	41.67	42.16	49.34
Ash	2.76	1.94	4.89	3.76	2.41	2.84	11.68	9.24	8.26	13.70	12.75	5.70
Sum	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
Total S	1.10	1.01	1.01	1.50	2.83	3.07	2.72	3.83	5.72	6.66	6.92	2.50
S. in ash	0.10	0.08	0.19	0.02	0.01	0.02	0.17	0.09	0.04	0.29	0.05	0.47
Volatile S	1.00	0.93	0.82	1.48	2.82	3.05	2.55	3.74	5.68	6.37	6.87	2.03
Iron 7-8 of volatile S *	.87	0.82	0.79	1.29	2.46	2.66	2.23	3.27	4.97	5.57	6.01	1.78
Fe_2O_3 5-4 of volatile S *	1.25	1.17	1.02	1.85	3.52	3.81	3.18	4.67	7.10	7.96	8.58	2.53
Clay (ash—Fe_2O_3) *	1.51	0.77	3.87	1.91	n 1.11	n 0.97	8.50	4.57	1.16	5.74	4.17	3.17
Marcasite 5-8 of S *	1.87	1.75	1.61	2.87	5.28	5.71	4.78	7.01	10.65	11.94	12.88	3.81
Corrected C. *	53 83	53.69	52.40	52.68	44.94	44.26	40.83	44.68	45.40	40.87	41.29	49.08
Hydrocarbon *	32.64	33.12	34.33	34.96	45.32	45.07	37.18	37.92	36.70	36.44	37.14	40.16
C	71.11	71.67	71.37	72.88	73.55	72.42	65.87	68.33	68.07	62.29	63 57	73.09
H	4.74	4.90	4.48	4.81	5.77	5.73	4.90	5.00	5.26	4.62	4.78	5.03
N	1.40	1.40	1.40	1.45	1.50	1.50	1.01	1.25	1.49	1.20	1.19	1.31
O	8.84	8.49	9.25	8.04	8.37	8.53	5.28	6.62	5.15	6.80	6.30	9.06
Heating Power by Williams' Calorimeter in B. T. U.	12,726	12,868	12,836	13,016	13,569	13,502	12,359	12,861	12,714	12,012	12,099	13,489
Calculated from ultimate analysis by Dulong formula	12,688	12,876	12,506	13,039	13,755	13,581	12,335	12,702	13,037	11,681	12,035	13,189
Heating Power in B. T. U. calculated from proximate analysis*	12,783	12,810	12,798	13,025	13,580	13,479	11,760	12,570	12,767	11,995	12,406	13,370
"H" in B. T. U*	147.47	148.50	148.25	148.64	150.88	151.76	158.37	156.67	156.29	157.39	158.59	....

* Computed from analysis by A. C. Lane. Phosphorus in No. 3, 0.012%; in No. 8, 0.017%; in No. 11, 0.014%.

TABLE B.—ANALYSES OF MICHIGAN COALS BY H. J. WILLIAMS, REFERRED TO DRY COAL.

Number	1	2	3	4	5	6	7	8	9	10	11
Volatile Comb.....*	38.9	37.6	37.7	38.6	49.5	49.5	42.1	42.2	42.2	41.7	43.5
Fixed Carbon.....*	60.0	60.2	57.0	57.3	48.0	47.5	45.1	47.9	49.0	43.8	44.2
Ash	3.07	2.17	5.30	4.07	2.55	3.02	12.79	9.81	8.79	14.42	13.3
Volatile S	1.11	1.04	0.89	1.60	2.99	3.24	2.80	3.97	6.04	6.71	7.2
C	79.14	80.23	77.40	78.86	77.90	76.98	72.16	72.55	72.49	65.57	66.6
H	5.28	5.48	4.86	5.20	6.11	6.09	5.37	5.31	5.61	4.87	5.0
N	1.56	1.57	1.52	1.57	1.59	1.59	1.10	1.33	1.59	1.26	1.2
O	9.84	9.51	10.03	8.70	8.86	9.08	5.78	7.03	5.49	7.17	6.6
	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000	99.9
Heating Power per unit dry coal calculated from result by Bomb Calorimeter	14,164	14,405	13,920	14,083	14,371	14,353	13,527	13,656	13,538	12,646	....

* Computed from analysis by A. C. Lane.

TABLE C.—ANALYSES FOR COMPARISON BY H. J. WILLIAMS.

Number	1	2	3	4	5	6	7
Location	Big Muddy.	Pittsburg.	Clearfield, Pa.	Pocahontas.	Mt. Olive Nut.	Hocking Valley.	Yorkville.
Moisture	5.79	1.49	0.44	0.55	4.82	5.42	1.44
Volatile Comb.	30.11	32.57	18.76	16.55	32.00	35.27	35.29
Fixed Carbon	55.79	57.87	73.15	76.94	49.50	52.79	53.06
Ash	8.31	8.07	7.65	5.96	13.68	6.52	10.21
(Lower figures, in dry coal.)	8.82*	8.19*	7.69*	5.99*	14.38*	6.90*	10.36*
Sum	100.000	100.000	100.000	100.000	100.000	100.000	100.000
Total S	1.03	1.13	1.02	0.81	4.48	2.09	3.42
S. in ash	0.13	0.02	0.11	0.12	0.22	0.14	0.03
Volatile S	0.90 0.96*	1.01	0 91	0.69	4.26 4.43	1.95 2.06	3.39 3.44
C *	71.81	75.57	80.17	82.85	63.21	74.63	72.28
H *	4.85	5.13	5.08	4.77	4.67	4.96	5.05
H-⅛ O *	3.41	4.04	4.49	4.22	3.12	3.71	4.19
N *	2.04	1.40	1.46	1.32	1.15	1.43	1.42
O *	11.52	8.70	4.69	4.38	12.16	10.02	6.85
146 C	10,490	11,020	11,700	12,100	9,240	10,890	10,630
620 (H — ⅛ O)	2,104	2,506	2,778	2,620	1,928	2,295	2,588
40 S	.036	.040	.036	.028	.255	.082	.138
Heating Power, Wet	12,120	13,680	14,490	14,780	11,100	12,420	13,310
Heating Power, Dry	**12,885**	**13,867**	**14,572**	**14,880**	**11,674**	**13,151**	**13,404**
Cal. Dulong†	*12,630*	*13,565*	*14,514*	*14,748*	*11,413*	*13,267*	*13,326*
	— 255	— 302	— 43	— 132	— 261	+ 116	78
Combustible	85.90	90.44	91.91	93.49	81.50	88.06	88.35

---

* Ultimate analyses and calorimetric results are referred to dry coals.

† By A. C. Lane.

TABLE D.—ANALYSES BY C. H. HILTON.

Number	1	2	3	4	5	6	7	8	9	10	11
Location	No. 1, Pere Marquette.	Standard.	No. 1, Somers.	Owosso Co.	Lower Verne.	Verne.	Sebewaing.	Michigan Co.	Grand Ledge.	Pinconning.	Rifle River Cannel.
Ash	3.30	2.26	5.65	3.52	9.15	10.10	8.33	15.15	10.14	12.23	9.33
Total S	1.10	0.91	1.01	1.11	3.62	4.76	5.80	6.92	4.61	1.04	7.00
S. in ash	0.10	0.03	0.19	0.02	0.03	0.10	0.05	0.25	0.04	0.03	0.43
Volatile S*	1.00	0.88	0.82	1.09	3.59	4.66	5.75	6.67	4.57	1.01	6.57
S. from Fe†	1.028	0.881	0.835	1.085	4.105	4.366	6.52	6.64	5.223	1.074	6.41
Iron	0.90	0.77	0.73	0.95	3.51	3.82	5.71	5.81	4.57	0.94	5.61
Volatile Matter	41.25	41.36	39.44	39.63	41.24	42.11	41.39	40.08	38.48	38.59	37.79
Heating Power	....	....	13,167	....	....	....	....	....	....	....	....

---

* By subtraction.
† By computation as eight sevenths of the iron, compare p. 59.

TABLE E.—ANALYSES BY A. N CLARK.

Number	1	2	3
Location	No. 1, Pere Marquette.	New Hope, Jackson.	Grand Ledge.
Moisture	10.40	5.20	7.00
Volatile Comb	32.40	45.65	39.10
Fixed Carbon	55.20	45.65	46.40
Ash	2.00	3.50	7.50
Sum	100.000	100.000	100.000
Total S	1.45	3.39	3.42
$Fe_2O_3 + Al_2O_3$	tr.	2.24	5.32

TABLE F.—PROXIMATE ANALYSES.

Number	1	2	3	4	5	6	7	8
Location	Sebewaing.	Corunna.	Saginaw.	Flushing.	Corunna.	Sebewaing.	Jackson Cannel.	No. 2, Pere Marquette.
Moisture	4.82	3.03	....	10.425	3.968	4.46	2.00	1.98
Volatile Comb	44.58	38.78	31.39	29.70	39.476	47.92	49.00	43.49
Fixed Carbon	41.52	43.44	63.78	52.365	45.319	40.45	45.00	53.20
Ash	5.70	11.17	3.79	6.575	8.549	4.04	2.00	.97
Total S	3.38	3.57	1.04	.935	2.688	.305	2.00	.394
Sum	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000?
Total Combustible	89.48	85.79	96.21	83.00	87.483	91.42	96.00	97.084
Volatile "	46.27	40.57	31.91	30.17	40.820	49.44	50.00	43.69
Fixed "	43.27	45.23	64.30	52.835	46.663	41.97	46.00	53.40
Ratio of fixed to total comb.	.493	.527	.668	.636	.534	.458	.477	.55

TABLE G.—PARTIAL AND PROXIMATE ANALYSES.

Number	1	2	3	4	5	6	7	8
Location	Munger.	Scotts, Kalamazoo Co.	Corunna.	Rifle River Cannel.	Rifle River, Lower.	Jackson.	Alpena.	Kniffin, Clinton Co.
Moisture	59.20	1.99	6.33	11.35	3.60		17.96	0.36
Volatile Comb.		40.03	35.46	35.80	40.00	44.		32.92
Fixed Carbon	32.22	44.89	45.45	41.10	55.40	....	6.49	28.76
Ash	8.58	13.29	12.04	11.87	1.00	....	75.55	42.96
Sum	100.000	100.20	99.28	100.000	100.000	100.000	100.000	100.000
S*	....	....	....	5.84	....	....	....	7.68
Ratio of fixed carbon to total combustible. ...	....	.528	.561	.535	.57	....	....	....

---

* In this and the following tables where no sulphur is reported, it was undetermined.