PART I.—GEOLOGY OF COAL.

I. COAL AS A ROCK.

Section 1. Composition of Coal.

1. Definition of Coal.—Coal is the name applied to a related group of massive, uncrystalline, black or brown bedded minerals or rocks, which are composed largely of carbon with some oxygen and hydrogen and a few other elements, and are economically important as fuel.

2. Composition of Coal.—Coal is by some writers treated as a mineral, by others as a rock. As coal lacks the definite chemical composition which minerals are generally considered to have, it will be treated here as a rock. Coal is a mixture of certain elements, or compounds of these elements. The principal element is carbon, a common form of which is charcoal. The diamond and graphite are other forms of the same element. Oxygen and hydrogen, the two gases which combined form water, are the next most abundant elements. With these are traces of the elements nitrogen, sulphur, and more or less of other substances that will not burn and are grouped together as the ash. The ash will include traces of silica, potash and soda, sometimes alumina and iron, and in impure coal some shale or dirt. The way these elements differ in different coals is shown in the following table:

3. Table Showing Composition of Different Coals.

		Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Analysts.
1	Coal, Eastern Pennsylvania....	90.45	2.43	2.45	......	......	4.67	Regnault.
2	Coal, Clay county, Ind	82 70	4.77	9.39	1.62	0.45	1.07	Cox.
3	Coal, Ohio	73.80	5.79	16.58	1.52	0.41	1.90	Wormley.
4	Coal, Breckinridge, Ky	68.13	6.49	5.83	2.27	2.48	12.30	Peters.
5	Coal, Bovey	66.31	5.63	22.86	0.57	2.36	2.27	Vaux.
6	Peat	59.47	6.52	31.51	2.51	......	....	Websky.

4. How the Elements Occur.—In studying coal it is found that while some of the matter is in the elementary stage, much of it is in the form of compounds. Thus, part of the carbon is uncombined, when it is known as the "free carbon" or "fixed carbon," while the rest

of it is combined, partly with the hydrogen, making the hydro-carbons, as marsh gas, tar, etc., and partly with the oxygen making the gas carbon monoxide. The hydro-carbons are gases or become so on heating. Part of the hydrogen and oxygen will be found combined in the form of water. The sulphur occurs principally as a simple compound with iron, forming the mineral known as pyrite, a mineral closely resembling gold in its yellow color. The "sulphur balls" frequently noticed in the coal are an impure form of the same mineral.

These elements and compounds may then be grouped as:

1. Fixed carbon,
2. Gases that will burn or the volatile combustible material,
3. Water, will not burn,
4. Sulphur, considered by itself for reasons given below,
5. Ash.

5. Proximate Analysis.—An analysis of the coal which shows the proportion of the above parts of the coal is known as a proximate analysis. It is easier to make than an ultimate analysis, or one which determines the proportions of the elements, and is much better for determining the value of coal for fuel purposes.

The subjoined table will give an idea of the variation of the above constituents in different coals.

Table Showing Proximate Analyses of Different Coals.

		Fixed Carbon.	Gas.	Water.	Sulphur.	Ash.	Analysts.
1	Coal, Eastern Pennsylvania	86.38	3.08	4.12	0.50	5.92	McCreath.
2	Coal, Clay county, Ind	55.25	39.85	3.40	......	1.50	Cox.
3	Coal, Pittsburg, Pa	54.56	37.74	1.79	1.50	4.47	McCreath.
4	Coal, Fountain county, Ind	47.50	47.00	4.50	......	1.00	Cox.
5	Coal, Carbon City, Colo	41.25	46.00	3.50	......	9.35	Cox.

Section 2. Chemical and Physical Properties of Coal.

6. Combustion.—The most valuable property of any coal is its power to produce heat by the oxidation or burning of its constituent parts. If these parts are examined it will be found that two of them will not unite with oxygen or burn, as they are already practically burnt substances, or highly refractory, the water and the ash. The weight of ash in any coal is that much unburnable matter and reduces

the heat value of the coal that much. The water not only reduces the heat value by not burning, but absorbs a part of the heat produced by the other components while being evaporated. The sulphur yields a small amount of heat, but its value in this direction is more than offset by its injurious effects in the commercial use of the coal, as will be shown further on.

The combustible volatile matter yields the most heat for its weight, but in the ordinary usage of coal much of this is lost. For most of the purposes to which coal is put the fixed carbon is the most valuable element. Future practice may modify or change the truth of this statement.*

7. IGNITING OF COALS.—In general it may be stated that those coals containing a large proportion of gas ignite readily, while those containing a small proportion of gas ignite with difficulty.

8. CAKING.—Some coals when heated have the property of softening, becoming viscid and running together into a solid mass. Coals are sometimes classed on this basis as "caking or cementing coals," and as "non-caking," "free-burning," or "splint coals." The former coal is generally preferred by the blacksmith on account of its forming a "hollow fire," and hence is sometimes referred to as "blacksmith coal." The term "blacksmith coal" is, however, often used in speaking of a part of a bed of caking coal on account of its freedom from sulphur and other impurities. In parts of Indiana a caking coal is spoken of as a "bituminous" coal in contrast with what are known as "block coals," which in general are non-caking or splint coals. In the general usage of the term "block coal" this may be misleading, as will be shown later. The caking or non-caking property of coals seems to be the result of physical conditions more than of chemical, as a comparison of chemical analyses of the two kinds of coal fails to reveal any constant and noticeable difference. If caking and non-caking coals be compared, it will generally be found: First, the caking coal is a bright coal, while the non-caking or splint coal has a dull fracture; second, the non-caking coal splits more readily parallel to the plane of bedding, and if these planes along which it splits be examined they will be found to resemble sheets of charred shavings still showing the fibre, like charcoal; and if one of these sheets be examined chemically it is found to resemble charcoal further in having a very high percentage of carbon. An analysis by Mr. Cox of the carbonaceous matter between the laminae gave as follows:

*See "Utilization of Coal," Part IV.

Fixed carbon	83.40
Gas	13.30
Ash, white	0.80
Water	2.50

These charcoal-like sheets are very abundant in a non-caking coal, and it is supposed that its non-caking property is due to their presence, as being almost like charcoal they will, of course, not run together, nor will they allow the more bituminous parts of the coal to run together.

9. Coking.—By heating a caking coal out of contact of air, or burning it with a very meager air supply, the volatile materials are driven off, leaving a hard cake, lighter than the coal used, though of somewhat greater bulk, and for certain uses very valuable as a fuel. Those coals which will thus make coke are often known as "coking coals." Practically all caking coals are coking coals, but not all will make commercially valuable coke.

10. Hardness.—Coals vary in hardness from 1.2 to 1.8. That is, from a little harder than talc, which can be scratched readily with the finger nail and is taken as 1 in the table of hardness, almost to the hardness of rock salt, which is taken as 2 in such a table. The hardness of a coal influences its value to a large degree. A soft coal crumbles readily in mining, entailing some loss; there is further loss in screening and handling, and a still further loss in shipping and delivering. Often soft coals of excellent quality and thickness are allowed to lie undeveloped, or at most supply only a local trade, because of the loss in shipping. Such coals can be made of value by proper treatment, as will be discussed in Part IV of this report. Often coals which appear hard and firm will soften and crumble to fine coal when exposed to the weather. This is due to the presence of sulphur and other impurities, or to the gas contained.

11. Fracture.—Coals vary greatly in fracture. The hardest coals break often with a conchoidal or shell-like fracture. More common are the coals breaking into more or less cubical blocks, sometimes with bright faces, often with dull, but most commonly with alternate bright and dull bands. Such coal tends to cleave along the dull lines when struck. Examined in the mine, it is found that the laminations agree with the bedding.

Section 3. Varieties of Coal.

12. BASIS FOR DIVISIONS.—Based on the differences above considered, different kinds of coal have, for convenience, been given different names. These are based principally on the different proportions of fixed carbon and volatile compounds contained.

13. ANTHRACITE or "stone coal" is coal number 1 of the above analyses. As shown, it has a high percentage of fixed carbon, from 78 to 88 per cent., with from 3 to 7 per cent. of volatile matter, usually some sulphur, and from 4 to 12 per cent. of ash. It usually has a high lustre, sometimes approaching metallic, a gray-black color, sometimes iridescent (peacock colors), a hardness of from 2 to 2.5, and when pure will weigh about 100 pounds to the cubic foot. It often has a conchoidal fracture. It burns with a feeble blue flame.

14. BITUMINOUS.—This is the most abundant coal, and is well known as a soft coal burning with a yellow flame and usually with much smoke. Coals 2 and 3 of the above tables are bituminous coals. As shown, they have a large per centage of volatile matter, often 40 to 60 per cent.; ash 1 to 8 per cent., usually less than anthracite; sulphur, 1 to 3 per cent.

Bituminous coals are usually divided into three groups: (1) Caking coal, as above defined; (2) "non-caking," or free burning splint coal; (3) "cannel coal." Bituminous coals are sometimes classed as "cubical" or "block" coals, from their tendency to break readily into cubical blocks. In Indiana, however, the term block coal is restricted to coals in which a regular system of joints is developed in a high degree.

15. CANNEL COAL is a lustreless, very compact and even textured coal with a large conchoidal fracture. It does not differ much in composition from ordinary bituminous coal, though usually having a larger percentage of gas, as shown in Coal (4) P. 3. It burns like a candle, whence the name, taking fire readily and burning with a yellow flame without melting. It does not smut the hands, and aside from its use as a fuel or as a source of gas, is used for many of the common purposes to which rock is put, for house and barn foundations, stepping stones, etc., as around Cannelsburg, in Daviess county. It is valuable as an oil and gas producing coal. Its difference from bituminous coal seems to be due to a difference in origin, as will be noticed later. Cannel coal often grades into bituminous shale, or even into non-bituminous shale.

16. LIGNITE or "brown coal" varies from brown to black in color, often shows woody structure, contains a large amount of moisture and other volatile matter, and is usually very soft and easily crumbled. Coals (5) of the above tables.

17. PEAT is the name given to the thick mass of vegetable matter occurring in swampy regions to-day, and which is believed to represent one of the first stages in the formation of coal. Coal (6) of the first table. In the northern part of the State peat beds are met with having a thickness up to 50 ft.

18. GRAPHITE is a carbonaceous deposit consisting practically of nothing but fixed carbon, and believed to belong to the coal series, though not used as a fuel.

19. INTERMEDIATE KINDS OF COAL.—No line can be drawn between the different kinds of coal, as all intermediate grades can be found. Thus, between anthracite and bituminous are recognized semi-anthracite or semi-bituminous coals according as they approach more nearly anthracite or bituminous.

20. KINDS OF COAL IN INDIANA.—Passing over the peat which occurs in certain parts of Indiana, all the coal of this State is bituminous. No anthracite coal is known to occur in Indiana, and the conditions seem to warrant the statement that anthracite will never be found in Indiana. All three varieties of bituminous coal occur here—caking, non-caking or splint, and cannel coal.

Section 4. Impurities of Coal.

21. SULPHUR.—Of the impurities in coal, sulphur is probably the most important, as it is the most injurious. A coal containing sulphur will not stand the weather, but will tend to slack and disintegrate. Such a coal will not bear transportation nor long storage, even under cover. The sulphur usually occurs in the coal as pyrite (iron sulphide), of a bright yellow color. Pyrite tends to take up oxygen from the air or from water, changing to iron sulphate, which readily crumbles. Sometimes this oxidation takes place so rapidly in the coal mine that spontaneous combustion results from the heat generated. Sulphur in the coal also tends to make the coal clinker and stick to the grate bars. A coal containing sulphur can not be used for blacksmithing or working iron, because the iron will take up the sulphur, thus becoming "short," that is, brittle and less easily worked.

22. PHOSPHORUS is also injurious to iron and will prevent any coal containing it from being used in metallurgy. Among the other impurities which go to form the ash are silica, potash, and sometimes alumina, as already noted.

23. The gas NITROGEN, being a non-combustible gas, adds that much weight without assisting the combustion, and to that extent acts as an impurity.

24. OXYGEN might be included under the same head in so far as it is an unnecessary ingredient; for, while it may be of value to assist the oxidation or burning of the carbonaceous part, that office can just as well be filled by the oxygen of the air.

25. The WATER, in like manner, has been shown to be an impurity viewed from the use of coal as a fuel.

II. OCCURRENCE OF COAL.

Section 1. The Coal Bed.

26. COAL OCCURS IN BEDS.—If we enter a coal mine by a shaft or slope which exposes the rocks, we note as we go down that the rocks of different kinds lie above each other in horizontal or nearly horizontal layers. When the coal is reached it is found to extend horizontally and parallel with the other layers. In some places the coal is exposed in the face of a vertical cliff (see frontispiece), where it is still more apparent that the coal is simply a bed or layer lying between other layers and having much in common with them, notwithstanding the difference in composition. It will be noted that when the other rocks of the cliff are not horizontal, but dip or slope up or down, the coal will dip up or down at the same angle. Again, if the thickness of the coal be accurately measured at convenient distances along the face of the cliff, it will be found to vary, sometimes considerably, particularly if the section is a long one. If the accompanying layers above or below be measured at the same time, they will be found to vary also, though probably not just as the coal did. Note also that the layers of rock and coal seldom have the same slope as the hill in which they are exposed, though sometimes a slight rise toward the center of the hill is noticed.

We are led to conclude that as far as Indiana is concerned the rocks lie in more or less nearly horizontal layers; that the coal occurs in similar layers, agreeing with the other rocky layers in position, and in variability.

27. Extent of Coal Beds.—It is not an unknown thing in the State, in places where coal mining has been carried on extensively for some time, to find connected mines where one may travel from one to several miles underground. The evidence in such a case is conclusive that the coal bed has at least that extent, especially when the coal has been personally observed with a lantern for the whole distance. Again, if a set of drillings, made more or less in a line, be examined, it will be observed that certain of the thicker beds of coal can be identified in one after another in succession, as shown on Plates XXIII, etc. In this way it is often possible to trace a coal bed across a county or even farther. Leaving our own State for a moment, if we should start from Pittsburg and travel up the Monongahela river, or any of its tributaries, we may note a conspicuous horizontal black band, broken at short intervals by openings from which tramways lead to long buildings or "tipples" extending out over the river. It is the well-known Pittsburg coal bed, and has been traced over an area 225 miles long by 100 miles wide. On the other hand, if we visit the Iowa coal field, we find it exceptional to be able to trace a coal bed more than four or five miles. Again, in Part III, are shown a number of deep borings in Knox and Daviess counties. Note that while near the top the thicker beds can be traced from one to another, the lower beds can not be so traced. Evidently, then, a coal bed may vary in extent from a few acres to several thousand square miles. In Indiana there seem to occur beds of both limited and of great extent.

In this report, where coal beds of different areas are correlated, we should not be interpreted as intending to imply thereby that beds so correlated extend continuously from one area to another. They may do so. It is possible that some of the main coal beds of Indiana do extend over several thousand square miles. But when the average thickness of most of the beds in Indiana is considered (in the neighborhood of four feet); when the fluctuations in thickness and character of the accompanying rocky layers, as well as that of the coal, is considered, and when the conditions necessary to the laying down of coal are considered (as given in the next chapter), it is difficult to conceive of the conditions necessary to the laying down of a coal bed as existing simultaneously and uniformly over all the coal field covering most of Illinois and part of Indiana and Kentucky so as to result in the deposition of a nearly uniform, continuous sheet of coal.

28. Coal Basins.—In the preceding paragraphs it has been stated in a general way that coal beds are of variable extent and thickness. Is there any regularity in these variations? From one standpoint there is not, still there is one factor that so constantly accompanies the coal that it must be considered as the normal method of coal occurrence and so should be considered here. That is the occurrence of coal in basins.

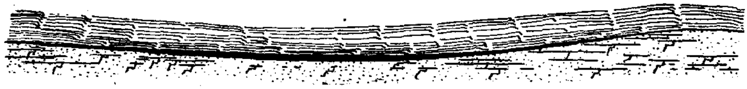

Fig. 1. Ideal Section of Coal in Basin.

If a bed of coal which still retains its normal condition be examined, it is found that

First—It has an area of greatest thickness from which it regularly becomes thinner in every direction. It may entirely thin out or it may simply become too thin to mine profitably.

Second—Where such a body of thick coal is of small extent, if a cross section be made of it, it is commonly found that the section of the coal has broadly the shape of a saucer as shown below, the thickest coal lying at a lower level than the thin coal.

The miners commonly speak of the part of the basin where the coal is lowest and thickest as the "swamp" and where it rises and becomes thinner as the "hill."

These basins may have an extent of only a few acres, when they are commonly known as "pockets." In Indiana, however, pockets are more commonly due to certain irregular causes, which will be discussed in a later chapter. In Crawford No. 1 mine, in Parke county, four small basins are being worked, each being drainless and requiring to be separately pumped from. More common are basins of from 20 to 30 acres up, each basin being worked by a separate shaft.

In Indiana it is a general condition that the basins increase in extent as we rise through the coal measures, so that in the lower bituminous beds in the upper part of the series the basin structure is hardly discernable, the original basin having covered several hundred to several thousand square miles, the coal maintaining over that area a remarkable uniformity of thickness and of detail (except as irregularly disturbed). Often clay bands a fraction of an inch thick, or even knife-edge partings are found over a coal basin of hundreds or thousands of square miles. This is well illustrated in Coal VI, as described beyond. Yet, if one of these beds be traced far enough it can be seen to gradually thin out, as illustrated by the group of sections showing feathering out of Coal VI between Coxville and Mecca. See Part II, Plate XI.

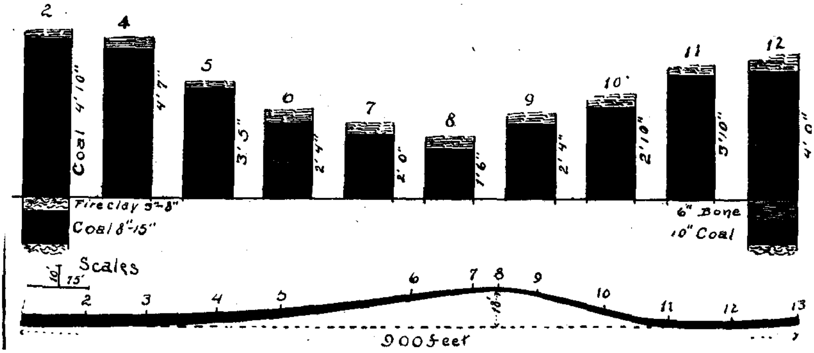

Fig. 2. Sections showing the thinning of the coal in passing from one basin to another. From measurements made in Crawford No. 1 mine, Parke county.

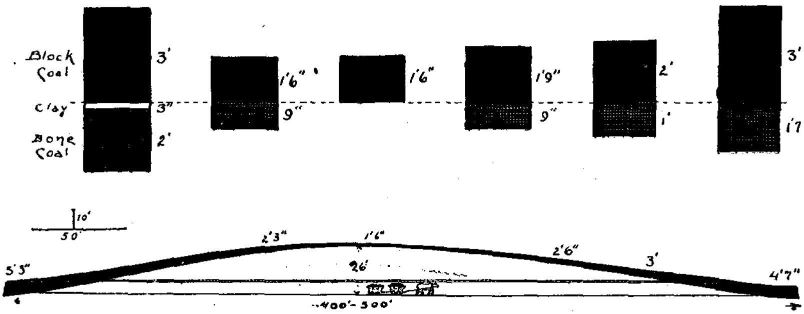

Fig. 3. Same, from measurements in Gartsherrie No. 5 mine in Clay county.

A coal basin can best be studied from a small basin. In Indiana no such perfect exposure of a coal basin in section has been found as was recently illustrated in the Geological Reports of Iowa,* but measurements were taken at a number of places in the mines showing practically the same conditions. Two of these are given by diagram here, illustrating the thinning of the coal over the hills. The first is from Crawford No. 1 mine, in Parke county, the second was obtained, partly from a 26-ft. cut, and partly from the air-course running parallel, in Gartsherrie No. 5 mine of the Brazil Block Coal Company, in Clay county.

* Iowa Geol. Surv., Vol. II, 1894, p. 53.

In these cases the entries were driven over the hills at points where the coal in crossing was thickest, drillings showing much thinner coal on top of the hill at other points.

In some cases the basins are widely separated and the intervening hill may be completely barren of coal. In other cases, and more commonly, the basins are fairly close together and at least a few inches of coal over the hills connect one basin with another. Sometimes places will be found between two basins where no marked hill exists and a good thickness of coal extends at that point from one basin to another.

29. COAL HORIZONS.—The constant recurrence of a similar succession of coals in borings and mine shafts, in which the coals from one to another bear about the same relative importance to each other, would seem to show that, if there are not continuous coal beds, there are at least widespread coal horizons. By a "coal horizon" we mean a particular horizon at which, over a more or less wide area, the conditions have been favorable for the laying down of coal, whether coal was laid down over all of that area or not. Take an illustration: Between 80 and 90 ft. below the coal bed so extensively worked in early days east of Washington, Daviess county, is very frequently found an impure limestone from a foot to four feet thick; below this are usually from a few inches to several feet of shales, either wholly black and bituminous or frequently with only the botttom few inches bituminous, and often splitting into thin sheets of some size. This shale usually carries fish scales and certain brachiopods. Immediately below this shale usually occurs a bed of coal, and below it in turn is a thick bed of fire-clay. This bed of coal is at points in that county over 7 ft. thick, and still thicker in adjacent counties, yet in places it is only represented by a black bituminous shale. In other borings not even that much may be found, and its horizon may be indicated only by the fire-clay and limestone, or even by the limestone alone. In such a case we identify a continuous coal horizon, though the coal bed is not only not continuous, but may be wanting over large areas.

30. THICKNESS OF COAL BEDS.—In estimating the thicknesss of a coal bed several methods may be followed. The first method, which seems to have been generally followed by the earlier survey on the coal of this State, is to take the average of single measurements made in each mine, or often to average the greatest thickness of coal at the different mines. Second, to take the average at each mine of all the coal being worked, by measuring the coal in each room being worked, adding, and dividing by the number of diggers, or where that has not

been done making an estimate from the orders given for posts of different length to support the roof, making due allowance if the floor is raised or the roof comes down before the posts are used. We have tried to follow this method in this report, with the result of reducing the average thickness in various districts from 6 to 18 in. from the earlier reports. In many mines lying idle or just opened a single measurement must suffice. Third, or true method, to average the coal over the entire area it covers. Practically this can not be done. The nearest approach would be an estimate based on mine measurements, as above, with the additional information to be gained from drillings of the unworked area.

An average of the coal being mined in Indiana would probably not be far from 4 ft. The "block" coal mines average 3 ft. 1 in. and the "bituminous" mines between 4 and 5 ft. The thickest coal being mined in the State is about 10 ft., the thinnest average of the mines on the inspector's list, 2 ft. 9 in., with "country banks" mining as low as 1 ft., or even less by stripping. Some of the coal beds maintain a thickness of from 5 to 8 ft. over considerable areas, while in other parts of the field they will be too thin to mine. The average of all the beds over the whole area would probably run well under 2 ft.

31. Thickness of Coal in Other Places.—As compared with other places, we find that in Alabama, out of 35 coal beds, 8 are over 4 ft. In Arkansas the mean thickness is estimated at 3 ft. In Illinois and Kentucky, about as in Indiana. In Iowa, 4½ ft. In Missouri probably the average would not be over 3 ft., though local "pockets" sometimes show a thickness of 20 or more feet over a few acres. In Michigan, 3 to 4 ft. In Ohio the beds average from 4 to 4½ ft. In Pennsylvania the "Mammoth" coal bed attains a maximum thickness of 50 to 101 ft., and above that is Coal F, 16 to 24 ft.; then Coal G, 15 to 16 ft., and so on, with some thin seams between, the total thickness at some places of all the beds being over 150 ft. The Pittsburg bed is about 10 ft. thick, ranging from 16 ft. to 2 or 3 ft., but usually has only from 5 to 8 ft. of workable coal.

In northeastern Canada coal beds are reported up to about 40 ft. in thickness.

In South Wales occur 100 coal beds, with a total thickness of 120 ft., 70 of these beds being worked. In the well-known Newcastle (Eng.) region the coal beds aggregate 60 ft. In Belgium the thickest bed is 3 ft. In Silesia occurs one bed 50 ft. thick.

32. Joint Structure of Coal. Block Coal.—Bituminous coal is sometimes called "block coal," from its property of commonly breaking up into cubical blocks. These blocks are the result of the exist-

ence in the coal of vertical cracks or joints, combined with a tendency of coal to split or break parallel with its bedding. In some coal these joint faces are only a few square inches or even less in area; in others they extend the whole depth of the coal and may have a lateral extent of scores of yards. In the first case the coal is apt to mine in small cubes of from a cubic inch up to a cubic foot or more. In the latter case the coal may be mined in great blocks the full depth of the coal bed, and too heavy to be handled. These joint faces may show no regularity of direction, or they may have nearly fixed directions for a hundred square miles. They would appear to be due to different causes.

Such joint faces are very common in other rocks in nature, especially being well developed in very fine-grained rocks, as shale or limestones. The finer the grain, as a rule, the more perfect and regular the system of joints. Where well developed, these joints are of great assistance in quarrying or mining. In shales such joints have been observed all over the coal area, and are known in other places to extend entirely through beds of shale 100 ft. or more thick, so that the bed will look as though some gigantic cleaver had cut it into cubes or blocks of up to thousands of cubic feet capacity.

Where such joints in rocks are very perfectly and regularly developed, it is found that there are two sets of joints more or less at right angles to each other. If the rock has a dip or downward slope it is found that one set of joints have the direction of the dip, and are known as the "dip joints" or as the "end" or "butt," while the others are at right angles to the dip, and since they follow the "strike" of the rock, are known as "strike joints" or as the "face," "slyne," "cleat" or "bord." It is found that strike joints and dip joints differ in this, that while the strike joint may be continuous for hundreds of feet, the dip joints commonly only extend from one strike joint to the next. In the coal of Indiana it is found that over most of the field the coal is broken up by irregular joints of small extent so that it mines out in irregular cubes of from a cubic foot or a little over, down.

Over a much smaller area, principally confined to the eastern margin of the coal field, these joints are developed in great perfection and with great regularity. In this State the term "block coal" is commonly restricted to such coal, and coal in which the joints are not regular is locally known as "bituminous."

Block coal may be a caking coal, a non-caking or splint coal, or cannel coal. It is most commonly a splint coal, and the two are sometimes, though erroneously, regarded as synonymous.

The miner commonly speaks of the joints as "slips," calling the strike joints "face slips" and the dip joints "butt slips."

The development of the coal industry of Indiana has been so intimately connected with "Indiana Block Coal" that we feel justified in presenting a somewhat detailed study of the peculiar characteristics of "block coal."

Block coal reaches its most perfect development and occurs in the largest basins in the region about Brazil, Clay county. In that area two beds are principally worked, known respectively as the "upper" and "lower block coal beds." A bed still above has been mined a

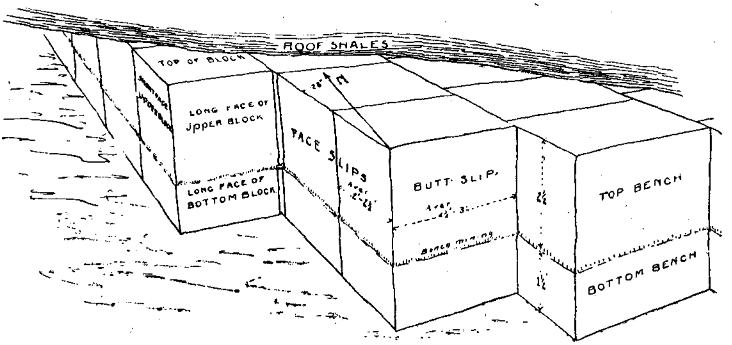

Fig. 4. Diagrammatic representation of "upper block" coal, as developed near Brazil.

little in two or three mines. It is commonly referred to as the "rider." In the following figure is shown in diagram the main normal characteristics of the upper block coal. These may be stated as follows:

1. Normally two sets of slips, face and butt. In places where the slips are only poorly developed it sometimes happens that only the face slips are developed with any regularity.

2. Face slips normally are continuous, often for considerable distances. On this account it has sometimes been the practice to drive the main entries parallel with the face slips.

3. Butt slips extend only from one face slip to the next.

4. Face slips normally have, in Indiana, the direction of N. 28°—30° W., the butt slips running N. 60°—62° E. These directions will hold with great persistency where the coal is in a large basin and not interrupted with irregularities. In very small basins, however, they may be very irregular. In general they tend to run parallel to the axis of a basin in its lowest part. In mining entries, where it is desired to run them in the thickest coal, which will be found in the "swamp" or lowest part of the basin, the proper direction can sometimes be determined by noting the direction into which the slips tend to bend

from their normal direction. This bending is only noted near the lowest part of the basin. Again, if a "hill" is approached, the slips tend to turn so as to be at right angles to it. Where entries are driven parallel to the slips it may result in their assuming an entirely new direction, often the change being so gradual as not to be noticed until the entry has been driven some distance. Their direction is also influenced by other irregularities in the coal, as will be described later.

5. Slips normally vertical. When the coal bed has been subjected to horizontal pressure, the slips follow the general law of joints in rocks under those conditions—they become regularly inclined to the vertical. In places in the block coal fields where the coal has been subjected to great horizontal pressure, as notably southwest of Asherville, Clay county, one set of slips may regularly be inclined 20° to 30° from the vertical, when they are commonly called "water slips." Again, if the coal bed is going to change its dip, it is frequently found that, if it is going to dip down, the top of the slip will dip so as to be at right angles to the new direction—that is, the top will bend away from the observer; if the bed is going to rise, the top will bend toward the observer.

6. Slips normally confined to coal. In cases where the coal is overlain or underlain by bone coal, even though separated by a parting of fire-clay, the slip will commonly run through it, as well as the main body of coal. As a rule, the roof will be smooth and unbroken, or if affected by joints, they will be found to be distinct from the slip in the coal. However, in the case of the inclined or "water slips," the joints extend indefinitely above and below the coal. Extending as they may above the coal to the surface they make convenient planes for the passage of water, hence the name.

7. Slips may, but as a rule do not, extend continuously through the coal. In the upper block coal there is a line of soft coal a foot or so from the bottom, at which the slips tend to offset a little. In the bottom block coal the offset is 6 to 18 in. below the top.

8. The slip may be "tight" and filled with some spar, so that the coal is as liable to break across the slip as to break with it, or it may be "open" so as to admit a knife blade. Sometimes the slips are open enough to admit the hand or even the arm, and cases are reported open to the extent of 10 in. or a foot. This usually occurs only near the outcrop of the coal. In Crawford shaft, old No. 2, north of Harmony, Clay county, it is said that in places it almost seemed as though one could crawl around between the blocks. Very often the blocks of coal are separated at the slip, but the space is filled with clay, or only occasionally with sand; they are then called "clay or mud slips."

Mr. John Andrews reports clay-filled slips 1 ft. broad in the old Eureka mine, a mile north of Brazil. It may be noted that even with these very open slips the roof is smooth and unbroken.

9. The distance between the face slips is usually somewhat greater than between the butt slips, so that "the long way of the block" is along the butt slip. The distance between the face slips will average from 2½ to 3 ft., between the butt slips 2 to 2½ ft. The largest blocks noticed were in Crawford shaft No. 1 (new), where the blocks are up to more than twice the usual size. The size of the block is thus about 2x2½x— thickness of bed, or 2½x3x— thickness of bed. The blocks are smaller when the bed gets thinner, in many cases.

10. Block coal generally tends to split parallel to the bedding very readily, but across the bedding with great difficulty. Such planes of splitting show very markedly the charcoal-like character spoken of in the preceding chapter. For the general appearance of block coal after being split up to facilitate handling, see plates in Part IV. When struck with the hammer these board-like blocks sound much as when a piece of wood is struck.

Section 2. Rocks Accompanying Coal.

33. The Sub-Coal Layer.—The characteristic layer underlying coal is commonly known as fire-clay, though often called fire-brick clay. It is usually a plastic, unctuous clay, containing some free sand. It may vary from a few inches to a dozen feet in thickness, though from 1 ft. to 3 or 4 ft. is more common. The fire-clay is usually white, often quite soft, though occasionally very tough, and usually has the property of resisting high temperature, whence the name. This is due to its being free from iron, sulphur and the alkalies, which act as fluxes, and rich in alumina, which is a highly refractory substance. Often these under-clays are filled with more or less nearly vertical or branching stem-like impressions.

Sandstone and shales are not infrequent under the coal, especially the former, and all intermediate grades are found, from a pure fire-clay through sandy fire-clay to what is practically sandstone. That this sandstone takes the place of the fire-clay is shown by its showing the stems penetrating it. This underlying sandstone thus taking the place of fire-clay when very fine grained is commonly known as "gannister," and in some places has been extensively ground down and used for the hearths of iron furnaces.

34. Shale Overlying Coal.—The strata overlying coal may be shale, sandstone, limestone or other rocks, but in a majority of cases is a dark or often black bituminous shale. In some cases the black shale is so full of bitumen or oil that it will burn and would pay to distill for oil. These overlying shales frequently show an abundance of plant remains—leaves, stems, ferns; and often the great flattened stems, of ancient trees, being many feet across and several score of feet long; showing perfectly the scars where the fronds were attached. In some of the mines of the State the roof appears to have been the site of a jungle, judging from the matted mass of well preserved plant remains shown.

Occasionally the black shale over the coal is cut by smooth vertical joints into rectangular blocks often of large size. Sometimes again these block will split parallel to the bedding into great rectangular sheets many feet in length and width while perhaps only one-fourth to one-sixteenth of an inch thick. Such shales were aptly called by Prof. Cox "sheety shales." This sheety shale usually appears to be a marine or sea deposit, containing generally fish scales and bones, sea inhabiting shells, etc., and frequently contains many concretionary boulders of pyrite, especially just at the top of and partially imbedded in the coal. Often these shales are so rich in bitumen that on drying by exposure to the air they show a decided tendency to bend or buckle. The suggestion is made that their bituminous matter comes from the underlying coal bed, possibly from the erosion of a shoreward portion of that bed or possibly in part from the top of the freshly deposited coal being stirred up by tidal action and finally redeposited with a large admixture of mud as a water deposit.

The concretionary pyrite boulders mentioned above, or as they are commonly known in the mines, "sulphur balls," "hard heads," or "nigger heads," often attain a diameter of 7 or 8 ft., and being very hard, seriously interfere with mining. Where they occur in the roof, they seem to be almost always associated with the black sheety shale, making the roof knobby and irregular, and extending down into the coal as far as 4 ft. below the regular top of the coal. In some mines they are distinct from each other and occur some distance apart, when they appear like the bottoms of black kettles attached to the roof. In other mines they do not appear as distinct boulders, but the black shale roof seems to be entirely concretionary in structure, the concretions of all sizes running together, and being as irregular on their lower face as the surface of violently boiling water, only on a vastly larger scale. These pyrite concretions are not usually regularly distributed; some parts of a mine will often be comparatively free from them, while in other parts of the same mine they occur in great abundance. In some places they are abundant in the body of the black shale, but do not project below its lower surface. While usually tending to come down when the coal has been mined from under them, in places they can only be brought down by the use of powder and with great difficulty.

35. Bone Coal.—A very common accompaniment of the coal, sometimes overlying, sometimes underlying, or found within the coal bed, is a substance, half coal, half shale, known as "bone coal," "rash coal" or "coal rash," "shaly coal," "slaty coal," "black jack," and by other names. It is a mixture of carbon as in coal, with shale in varying proportions. On the one hand it may change to a pure coal, on the other to a bituminous shale, and on over into a non-bituminous shale. It may be so rich in coal as to be almost undistinguishable from coal until burnt, when, instead of leaving a small quantity of ash, it may leave in the stove a chunk a little larger if anything than the original. When broken across the bedding, if of poor grade, it will look like shale with fine streaks of bright coal through it. If very rich, when broken across the bedding it may have the bright black fracture of pure coal, but if split parallel to the bedding it will be found to split easily and to show a smooth surface like shale or a school slate, instead of the usual carbonaceous or rough surface of coal. The presence of bone coal in or associated with a regular bed of coal detracts greatly from the value of the good coal, due to the fact that usually it is impossible to prevent some of the bone coal becoming mixed with the pure coal during the operation of mining. This fact should be kept in mind in estimating the value of a given bed of coal for purposes of mining. Many coal beds make an excellent showing when mined on a small scale, where proper care and oversight may be exercised and the bone coal kept out of the coal sold; but when mined on a large scale it becomes very difficult or impossible to exercise the same careful oversight, and the character and reputation of the coal suffers as a consequence.

36. Other Rocks Associated with Coal.—Beside the fire-clay and more or less bituminous shales, there are also associated with coal and making up the larger part of what is known as the coal measures, light-colored shales, sandstones, limestones and iron ores, with smaller quantities of other rocks, as chert.

37. Shales.—Of the rocks just mentioned, shales predominate in the coal measures of Indiana. The bituminous shales have just been described. These usually grade into the lighter colored shales, the

predominating colors being drab, blue or gray. When freshly exposed they are usually hard and tough and more or less massive, requiring to be blasted or worked much as the seemingly harder rocks. As soon as exposed to the weather they soften and crumble into a mass of more or less plastic clay. This is commonly called "slacking." In composition these shales may be nearly pure clay shale with an unctuous or greasy feeling, when they are commonly known as "soapstone" (strictly soapstone is a mineral that is not known to occur in Indiana), or, by the addition of sand in larger and larger quantities they may gradually grade over into a shaly or argillaceous sandstone, or even into a pure massive sandstone. On the other hand, by the increase of limy matter, they may grade over into limestone. Continuous beds of shale from 50 to 75 ft. thick are of common occurrence, such shales usually being rather light colored. Some shales characteristically divide into thin flakes or leaves, when they are called "fissile shales." Again, many shales, when mined, break up more or less into little cubes. Of these two the latter are generally more suitable for making brick. It is also found that a somewhat sandy shale is better for making brick than a pure clay shale, as the latter tends to shrink and lose its shape in burning.

A sandy shale may be largely made up of sand particles, but so fine that they are not recognized by the naked eye and the shale would pass as a clay shale unless carefully examined. From this the sand grains may increase until, on the most casual examination, it is evidently a sandy shale. A more or less even mixture of sand and clay that might with equal propriety be called a sandy shale or a shaly sandstone is quite common in the coal measures. Its presence often leads to an apparent disagreement where two persons report on the same section of rocks, as it is apt to be quoted as one or the other, according to the personal practice of the writers. This may explain many seeming disagreements when the present report is compared with other reports.

Especially in the northern part of the coal field there is abundantly found a peculiar combination of shale and sandstone known as "fake," "sand slate" and by other less common names. It consists of thin alternating layers of sandstone and shale, the layers often being like thin flakes, and giving a markedly banded appearance to a fresh cross section of the stone. A weathered bluff of it closely resembles a bluff of fissile shale, as the shaly flakes tend to weather out, leaving the thin projecting flakes of white sandstone, but with a coating of the dark shale which makes them appear as shale until broken across. In the block coal field this rock often immediately overlies the coal, making the roof. In such cases it presents several peculiarities, among which may be mentioned that it shows a greater tendency to "cut" and flake down in narrow places, like the entries, than in broad places, like the rooms; and in falling, instead of falling so that the space rises perpendicularly above the coal with a more or less nearly level top, as most shales do, it tends to come away in small flakes, leaving the roof arch-shaped with a peculiar and characteristic breaking down along the center of the arch, resembling in a striking manner the partial breaking up of the surface of the ground by a mole, only of course on a much larger scale and inverted.

The term "fake" has been used in our notes while making the survey as a convenient term, and its use in the report will apply to the rock just described.

In many places under or overlying a bed of limestone will be noticed a shaly-like layer, though usually lacking the stratification of a shale. It was commonly reported as "clod" or marl in the earlier reports. Examination frequently shows it to contain fossils similar to those contained in the accompanying limestone. It will also usually be noticed that the line of contact between it and the limestone is very irregular; indeed, in some places the limestone loses entirely the character of a layer and appears as lenticular masses or boulders in the structureless shale or "clod." In such cases it is evident that the clayey shale is only the residuum left by the decomposition of the limestone. In some cases this entirely replaces the limestone, and should then be recognized as of the same horizon.

The term "slate" is frequently used by persons in the coal field, but those using it differ greatly as to what is meant by the term, much as they do in defining soapstone. Slate has a definite meaning in the markets as well as in the nomenclature of scientific terms, and as slate as so defined is not found in Indiana, the use of the word will be avoided in this report.

38. SANDSTONE.—The sandstones are next to the clays in abundance in the coal area. As a rule the sandstones of the coal area of Indiana are shaly and crumble readily, not being valuable for building purposes. In one horizon, however, and locally in other horizons, the sandstone is purer, massive, and will resist weathering, and locally has the other requisite properties for a building stone.* In Indiana, as with many of the other coal areas, the main sandstone horizon lies near the bottom of the series of rocks containing coal, and in Indiana along the eastern edge of the coal area. In places in this horizon the

* Geol. Surv. of Ind., 1895, pp. 186-368.

sandstone becomes a coarse grit and is strongly cross-bedded. Cross-bedding is apt to be a characteristic of sandstone associated with the coal. Often those sandstones higher up in the coal series will appear quite thick and massive at one locality, while a short distance away they are replaced by shales, or no trace of them appears. It is quite a common thing with sandstone in the coal measures that its lower surface does not lie smoothly and evenly upon the layer below, but the contact is more or less irregular. In some cases the contact is only very slightly wavy, in other cases the underlying rock seems to have been carved into little hills and valleys before the laying down of the sandstone, and sometimes it will be observed that the sandstone occurs only in the hollows carved in the underlying rocks. One of the principal sandstones of the coal measures of Indiana occurs most commonly in such a way, often presenting a thickness of from 75 ft. to 200 ft. in these hollows cut in the underlying rocks, while outside the hollows it may have a thickness of only 10 to 50 ft., or not be recognized at all. This sandstone, however, as at Coxville, Mecca, Silver Island, etc., may prove to be entirely of later age than the coal-bearing rocks. This sandstone has been largely quarried in Indiana.

39. Limestones.—Limestones form but a small part of the strata associated with coal. They seldom exceed four to five feet in thickness, but, notwithstanding, are often remarkably persistent over large areas, and thus may be of great assistance in correlating the coal beds. The limestones of the coal measures are generally very impure, sometimes sandy, sometimes shaly, often dark-colored or black from the presence of bituminous matter. These impure limestones are quite commonly called "bastard" limestone in the coal regions. As already described under shales, they will sometimes decay, the lime being dissolved out, leaving behind a sandy or shaly or mixed layer to take its place, the small shrinkage in such cases showing how largely the limestone was composed of shale or sand. Generally the limestone beds are quite distinct, but sometimes they are found to grade over into calcareous shales both horizontally and vertically. The limestones are usually quite full of shells or fossils, and an examination of these shells reveals that they are all shells found only in the sea. It may be of interest to note that the black sheety shale frequently associated with limestone in the coal measures also shows marine fossils, cephalopods, fish remains, etc.

40. Grit, Conglomerate.—As already mentioned, the sandstones of the coal measures are usually coarse-grained and cross-bedded, showing evidence of having been deposited by rapid currents. Locally

the coarseness increases until quite a proportion of the grains are small pebbles up to a half inch or an inch in diameter. This is especially true of the massive sandstone just within the eastern edge of the coal area. In a few places true conglomerates are met with. These are usually quite limited in extent and generally occur just at the bottom of a sandstone bed, and in connection with what are called nonconformities.

41. TYPICAL SECTION.—With the exception of the fire-clay which usually underlies the coal, and the black shale which usually overlies the coal, the shales, sandstones and limestones do not seem to follow any marked order of succession. This is evident from an examination of the columnar sections given beyond. The varied relations of the different strata to each other and to the coal, the proportion of coal to the other rocks and many other features in connection with the occurrence of coal can well be studied in the following record of a deep well bored at Vincennes, Knox county. This is believed to pass entirely through the coal measures at about their deepest point in Indiana. The boring being done with a core drill and by experienced drillers, is probably as reliable as any record can be made.

The writer has in part verified the record by examination of the cores obtained.

		Thickness of Strata.		Coals and Spaces.		Depth.	
		Ft.	In.	Ft.	In.	Ft.	In.
1	Soil	2	0				
2	Sand and gravel	40	0				
3	Gravel with mixture of clay	17	0				
4	Hard cemented gravel	4	3	71	3	71	3
5	Sandstone, soft, yellow	9	0				
6	Sandstone, light	45	1				
7	Sandstone, mixed with clay shale	1	0				
8	Sandstone, light colored	15	5				
9	Shale, blue clayey	23	8				
10	Shale, dark clayey	4	0				
11	Shale, clayey and sandy mixed	54	8				
12	Sandstone, gray	12	3				
13	Shale, black	1	8	166	9	238	0
14	COAL	**0**	**7**	**0**	**7**	238	7
15	Shale, soft clayey (fire clay)	1	6				
16	Shale, hard blue, clayey	4	0				
17	Shale, light colored, clayey	3	0				
18	Shale, brittle, clayey	7	11				
19	Shale, red	2	0				
20	Limestone and clay shale mixed	2	9				
21	Shale, clayey	3	6				
22	Shale, red	3	0				
23	Shale, clayey, streaked with limestone	6	0				
24	Limestone	5	0				
25	Shale, clayey	1	7				
26	Shale, sandy	39	1	79	4	317	11
27	COAL	**0**	**9**	**0**	**9**	318	8
28	Shale, sandy, streaks of sandstone	22	9				
29	Sandstone	25	3				
30	Shale, hard, clayey	16	2	64	0	382	10
31	COAL	**4**	**1**	**4**	**1**	386	11
32	Shale, very soft, clayey, limestone spots	13	8	13	8	400	8

		Thickness of Strata.		Coals and Spaces.		Depth.	
		Ft.	In.	Ft.	In.	Ft.	In.
33	COAL	**2**	**11**	**2**	**11**	403	7
34	Shale, clayey	0	7				
35	"Hard stone"	1	5				
36	Shale, dark	0	3	2	3	405	10
37	COAL	**2**	**9**	**2**	**9**	408	7
38	Shale, dark	0	2				
39	Shale and coal mixed	0	2				
40	Shale, soft, clayey	2	0				
41	Shale, hard, clayey, with lime	3	6				
42	Shale, light, clayey	10	0				
43	Shale, sandy, with layers of sandstone	28	5				
44	Shale, dark, "slaty," with limestone bands	14	4	58	7	467	1
45	COAL	**1**	**9**	**1**	**9**	468	10
46	"Hard rock"	0	3				
47	Shale, clayey	5	0				
48	Shale, coarse brittle, clayey, limestone streaks	1	7				
49	Shale, black	1	8				
50	Shale, clayey	0	10	9	4	478	2
51	COAL	**3**	**9**	**3**	**9**	481	11
52	Shale, soft, clayey	3	0				
53	"Hard rock with streaks of lime"	2	0				
54	Shale, sandy and clayey mixed	13	1				
55	Sandstone, soft, yellow	11	9				
56	Sandstone, light colored	9	8				
57	Shale, sandy, with thin layers of sandstone	4	8				
58	Shale, sandy	36	9				
59	Shale, blue, clayey	30	2				
60	Shale, slaty, black, with limestone bands	8	6	119	7	601	6
61	COAL, cannel, mixed with bituminous shale	**2**	**1**	**2**	**1**	603	7
62	Shale, dark colored	0	10	0	10	604	5
63	COAL	**1**	**1**	**1**	**1**	605	6
64	Shale, soft, clayey	0	6				
65	Shale, hard, sandy	3	6				
66	Shale, soft, sandy	5	0				
67	Shale, clayey	4	9	13	9	619	3
68	COAL	**0**	**9**	**0**	**9**	620	0
69	Shale, soft, clayey	2	7				
70	Shale, black, mixed with coal	0	5				
71	Shale, hard, clayey	0	1	3	1	623	1
72	COAL	**2**	**0**	**2**	**0**	625	1
73	Shale, coarse sandy, with dark shale	12	0				
74	Shale, dark blue	22	0				
75	Shale, black, "slaty"	10	0				
76	Coal, mixed with shale	0	2	44	2	669	3
77	COAL	**0**	**10**	**0**	**10**	670	1
78	Shale, soft, clayey	4	2				
79	Shale, hard, clayey	4	4				
80	Shale, soft, clayey	2	6				
81	Shale, black, "slaty"	3	10	14	10	684	11
82	COAL	**3**	**10**	**3**	**10**	686	4
83	Shale, soft	0	6				
84	Shale, hard, blue clayey	7	0	7	6	693	10
85	COAL	**0**	**6**	**0**	**6**	697	7
86	Shale, hard, dark blue	0	7				
87	Shale, black, clayey	0	7	1	2	695	6
88	COAL	**3**	**0**	**3**	**0**	698	6
89	Shale, light clayey	1	6				
90	Shale, dark	0	8				
91	Shale, clayey	6	0				
92	Shale, sandy	5	4				
93	Shale, clayey	6	0				
94	Shale, black	2	0	21	6	720	0
95	COAL	**0**	**1**	**0**	**1**	720	1
96	Shale, black	0	10				
97	Sandstone, soft, brown	1	0				
98	Sandstone, gray	0	6				
99	Sandstone, soft, brown	3	0				
100	Sandstone, gray	4	2				
101	Shale, sandy	9	8				
102	Shale, clayey	9	10	29	0	751	1
103	Shale, black, and coal	2	0	2	0		
104	COAL	**1**	**1**	**1**	**1**	754	2
105	Shale, soft, clayey	4	4				
106	Shale, sandy	8	9				
107	Sandstone, soft, gray	9	1				
108	Shale, sandy	25	6	47	8	801	10

Taken as a whole, the section shows most strikingly the lack of regularity, which is one of the most characteristic features of the coal and associated rocks. In thickness the coal beds vary from 1 in. to 4 ft. 1 in., some of them in succession being 7 in., 9 in., 4 ft. 1 in., 2 ft. 11 in., 2 ft. 9 in., 2 ft., and so on. Notice also that there is not only no regularity of thickness but no regularity of increase or decrease of thickness as the depth increases. The common idea that the coal beds get thicker at greater and greater depths is quite evidently not sustained by this section, and a comparison of the different deep borings given beyond shows that the idea is entirely erroneous. Of interest here as showing the lateral variation is a comparison of Coals 33 and 37 and the space between as found in this boring and as found in two shafts sunk only a short distance away. In one of these shafts the section is as follows:

	Ft.	*In.*
COAL	5	3
Shale, etc.	0	8
COAL	2	0

In the other shaft the section of the same coal is:

	Ft.	*In.*
COAL	2	0
Shale	0	4
COAL	4	0
"Rock"	1	6
COAL	2	0

This coal crops out on the eastern side of Knox county, and a typical section at Edwardsport is as follows:

	Ft.	*In.*
COAL	2	6
Parting	0	½
COAL	0	9
Parting	0	¼
COAL	2	0
Parting	0	1
COAL, poor	0	10

A little farther east in Daviess county the same coal shows no partings, the section being:

COAL	5 ft.

These sections show clearly the variability of a coal bed laterally.

To take up next the spaces between the coals, the same lack of regularity is apparent. These spaces vary from 1 ft. 2 in. to 119 ft. 7 in. A series of these spaces, omitting the inches, would be as follows: 79 ft., 64 ft., 13 ft., 2 ft., 58 ft., 9 ft., 119 ft., 10 in., and so on. Comparing the spaces with the thickness of the coals it can be seen what a small proportion of the thickness is coal. Thus, out of the 800 ft. the coal occupies 32 ft. 7 in., or about one-twenty-fifth, or, considering only the space between the first and last coal, about one-twenty-first is coal. This may be shown in another way by comparing a number of the coals with the space to the next coal above. Thus: Coal 27 is less than one-one-hundredth of the space above in thickness; Coal 31 is about one-sixteenth of the space above it; Coal 45 is about one-thirty-fourth of the space above it; Coal 51 is between one-half and one-third of the space above it; Coal 61 is about one-fifty-seventh of the space above it, and so on.

Examining next the composition of the spaces it will be noticed that most of the coals are underlain by what is described as "soft clay shale," most of which would commonly be designated fire-clay. Coal 45, however, is underlain by "hard rock." In this section all the coals are overlain by shale or fire-clay, in a majority of cases the shale being black or dark. Examination of the sections given beyond does not show such uniformity. The preponderance of shale in the coal measures is well shown in the section. Examining the sections for any uniformity in order of material we find above Coal 27 shale, limestone, shale, limestone, shale to next coal above. Above Coal 31 comes shale, sandstone, shale. Above Coals 33 and 45 only shale. Above Coal 51 shale and "hard rock." Above Coal 61 shale, sandstone, shale, "hard rock" (limestone and chert?), shale to coal above, etc. The only regularity here shown is that coal is usually associated normally with shale, sandstone and limestone seeming to require quite different conditions for their laying down than the coal, the shale apparently requiring conditions more nearly similar to the conditions for making coal.

III. ORIGIN OF COAL.

42. ORIGIN FROM PLANTS.—It is the generally accepted belief that coal is of vegetable origin. What is the evidence that has led to that belief?

43. TESTIMONY OF PLANT REMAINS.—Nearly every miner has recognized the presence at the top of the coal bed or in the shale overlying, impressions and remains of leaves and stems of plants. Sometimes these overlie the coal in the greatest profusion. Often are found preserved in great perfection the fronds of delicate ferns, at other times the leaves of less familiar plants. Sometimes, too, the impressions show surfaces of some length covered with a regular network of peculiar-looking scars.

In many of the mines where the coal has been stripped, or in quarrying the sandstone associated with the coal, trunks of large trees rise from the coal bed, their roots being imbedded in the fire-clay. Mr. Kindle* mentions such an one at the Moore quarry, in Indiana, near French Lick, where one trunk 12 in. in diameter was exposed to a height of 6 ft. In this case the bark was "altered to coal," while the interior of the trunk had been replaced with sandstone. This quarry has disclosed several such trunks standing upright, and similar trunks have been met with at other places through the coal area of this State. Such tree trunks are found in Ohio, Pennsylvania, and in connection with the coal beds in most of the coal areas. Sometimes such trunks have a length as high as 75 ft., and they have been found 3 ft. in diameter. Again, in places trunks and stems of large plants are found in such crowds as to suggest an old jungle. Furthermore, it is not uncommon to find stems and other vegetable remains in the coal itself. As a rule, these trunks are not of familiar trees, but resemble the ferns and tree ferns, the scouring rushes or horse tails, some plants now only known in the tropics, and some plants which do not exist at present. These facts all testify that, whatever its origin, coal was laid down in the presence of vegetable growth, in many cases having been laid down about the foot of growing trees and shrubs.

44. TESTIMONY OF COMPOSITION, STRUCTURE AND VARIATION.—Wood is about one-half carbon and the other half oxygen and hydrogen in about the ratio of 22 of oxygen to 3 of hydrogen. In addition to these there is about 5 per cent. of ash, which, on analysis, is found to be made up principally of silicia and alumina, with some

*Twentieth Annual Report, 1896, p. 349.

lime, iron trioxide, chlorine and oxides of potassium, sodium, magnesium, manganese and phosphorus. Comparing this with the first table of analysis of coals it is evident that the main difference is one of proportions, the coal having a higher percentage of carbon and less oxygen and hydrogen. In the case of peat, which is universally recognized as vegetation, the difference in percentage is not very marked. Thus a light-brown peat, as analysed by Websky, gave practically the same composition as wood, a dark-brown or black peat gave 59 per cent. of carbon and a correspondingly smaller amount of oxygen and hydrogen. Lignite or brown coal, which is often readily seen to be a charcoal-like mass of stems and vegetable matter, gives 64-65 per cent. of carbon, with another decrease of hydrogen and oxygen. The cannel and bituminous coals are but a step further, the carbon having risen to from 70-85 per cent., and if microscopic slides be carefully and properly made, the peculiar cell structure of plants can usually be made out, even of bituminous or anthracite coal. In anthracite the carbon has increased to 90 per cent. or over. In graphite there is nothing but carbon left, or the carbon forms 100 per cent. In these cases we could consider that there was an increase in the amount of carbon, or we would get the same result by withdrawing the hydrogen and oxygen, for then the proportion of carbon would increase as the gases decreased.

A very simple experiment may be performed which is suggestive of how these differences might be brought about. If a piece of wood be heated in a closed vessel, preferably of glass, as a test tube, it will be noted first that moisture collects on the sides of the test tube, and then for a moment a white cloud like steam rises from the end of the tube. Examination will show that it is steam. If the operation be stopped at this point it is evident that the wood now contains a smaller percentage of oxygen and hydrogen, since some of these elements have passed off in the form of water, and a corresponding increase in the percentage of carbon. The wood now corresponds about with peat in composition. If the operation be continued, it is quickly noticed that gases are coming off which will burn if a match be applied, and a black, tarry-looking substance begins to collect near the top of the test tube. If tested, the combustible gas will be found to be similar to the combustible volatile matter driven off from a soft coal, the tarry substance being the same as the tar obtained from coal at the gas works. If the operation be stopped at different stages while the gas is being driven off, the wood will be found to agree in composition with different grades of bituminous coal, or, toward the last, with anthracite coal. If all the gas be driven off there is left pure carbon in the form of charcoal, which agrees in composition with graphite. In this experiment the change has been produced by high heat in a short time. A low heat extending over a long time tends to produce the same changes.

Instances are known where timbers left in deserted mines for several hundred years, shut off from air and soaking in water, have been found changed to true brown coal.*

45. CONDITIONS OF COAL FORMATION.—If wood decays in the air, the carbon unites not only with the oxygen of the wood but also with the oxygen of the air, so that all the carbon may unite with oxygen and pass away in the form of gas. When, however, it decays under water or earth, much of the carbon must remain uncombined and the gases formed will remain or not according to the completeness of the protection afforded by the covering. Thus, in a region long covered with forest, the vegetable remains may amount to only a few inches, while in a swamp near by there may have accumulated 40 to 50 ft. of vegetable matter, as is often found when such swamps are drained, or the attempt is made to build a railroad over one. Such an accumulation of half-decomposed vegetable matter is called, if impure, muck; if more pure, peat. Usually such accumulations result mainly from the growth of spongy mosses of the genus Sphagnum. Such peat beds in formation are abundant to-day, often covering several hundred square miles and 50 ft. or more deep.

A study of all the facts leads to the conclusion that in past times the conditions have been more favorable for vegetable growth than to-day. That from time to time fresh water swamps or series of swamps covered vast areas, usually, it is supposed, near the sea level and border. That, following a period of swampy conditions, the land surface would rise, allowing the accumulated peat to be washed away, or it would sink, allowing the ocean to cover the bed with mud and sand, and occasionally beds of limestone to be laid down upon the coal.

We would then have, in addition to the decomposition going on, a steady consolidating under the weight of the mud and sand being laid down. When the filling has gone far enough, or if the land rises a little, the conditions favorable to coal formation may return and another bed of peat be laid down. This may continue until several hundred feet of peat, mud and sand have accumulated, and under the pressure and heat from the interior of the earth have begun to turn to coal, shale and sandstone, respectively. Let this process go on for untold centuries, and the coal will slowly lose more and more of the volatile con-

*Zeits. d. deutsch. geol. Gesel., Band, XXV, 364-366, 1873.

stituents, and become much reduced in thickness and increased in hardness, and the shale and sandstone will become firmer and harder. It has been estimated that one foot of coal represents from 6 to 8 ft. of closely compacted vegetable matter.

The impurities of the coal may in many cases come entirely from the plants, or they may have been washed in. As regards the first case, it has been found that all the impurities of a good coal occur in the ash of plants and are there in sufficient quantity. The freedom of the fire-clay from impurities has already been mentioned. An ordinary clay contains iron, potash, soda and other impurities. The carbonic acid formed by the overlying vegetable matter acts upon these substances, the iron in the form of iron oxide is partly reduced, in which condition it can be carried away in solution; the alkalies are also removed by this acid. So that the fire-clay underlying coal is in itself testimony for the vegetable origin of the coal, the impurities of the clay having in large part been transferred to the coal through the action of the vegetation which formed the coal.

46. ORIGIN OF CANNEL COAL.—The evidence is strong that most coals were formed from vegetation growing where the coal occurs. In the case of cannel coal, however, the coal seems to have been deposited much as a shale is deposited. That is, it is simply a consolidated layer of fine carbonaceous mud. Cannel coal is believed to be a deposit made in the more open deep water-ways of the coal swamp by the washing in of finely comminuted vegetable matter from other portions of the swamp. Having such an origin, it is evident that clay mud may also be washed in and the cannel coal may grade over into bituminous shale, or even into light-colored non-bituminous shale, or the clay mud may be washed in at the same time as the carbonaceous mud, making the coal too shaly to be used for fuel purposes. As a matter of fact, that is what occurs in the majority of cases, so that while oily, bituminous shales or very impure cannel coal is not rare, it is only rarely that the conditions have favored the washing in of carbonaceous matter only, without the clay, resulting in a pure cannel coal. Cannel coal is apt to be a local deposit of variable thickness.

Some of the local evidence upon which this theory is based may be given. At a cut on the E. & R. Ry., near Burn City, Daviess county, occurs an impure cannel coal. It is reported by those in the neighborhood who have burned the coal that it did not seem to make any more ashes than other coals. A few feet higher this has graded over into a coal similar in appearance but which leaves about half its original bulk as ash. Still higher, the black color gradually turns to gray, and the coal has graded over into an ordinary gray clay shale.

Again, over the Alum Cave coal, is frequently a cannel-like bituminous shale, in which fish scales are abundant, indicating the prevalence of open water conditions at the time. Again, if a piece of the cannel coal from Cannelburg be examined closely, it will be seen that it does not show the alterations of bright and dark lines referred to above; they more closely resemble a very fine-grained black shale in structure. Where the beds are examined the cannel coal beds are more distinctly stratified like other rocks. Occasionally skeletons of leaves are found in cannel coal, giving evidence of transportation. And finally, deposits similar in appearance and properties to cannel coal are often found being deposited in the open water of the swamps and marshes of to-day.

IV. COAL—PRESENT POSITION AND STRUCTURE.

47. Coal Subject to Many Irregularities.—It is a common impression among those not well acquainted with the actual occurrence of coal, that it generally lies in horizontal sheets between horizontal sheets of the associated rocks, much as a black blanket might be spread out between a number of other blankets of different colors. Experience has shown, however, that such regularity seldom exists, and a surprisingly large percentage of the cost of mining coal can be credited to these irregularities. These irregularities are of three classes, named in the order of their importance:

1. Irregularities of original deposition.
2. Irregularities due to subsequent erosions.
3. Irregularities due to the differential movements of the earth's crust.

Section 1. Irregularities of Original Deposition.

Under this head will come a certain kind of variation in thickness and of level, due to the coal having been originally deposited in basins. As already described in I, in a coal basin the coal is normally thicker in the center of the basin and thinner on the edges. At the same place was described the elevation of the coal bed over the dividing ridge between two coal basins. While these two conditions are usually normal, the extent and shape of these basins, as well as the thickness and quality of the coal, are subject to great variations. As already pointed out, a basin may have an extent of only a few acres or of several hundred square miles. A mine started in it may be "worked out" in a few months and not pay the cost of starting, or it may be worked a score or more years, or until the limits of the company's territory have been reached in every direction. In shape a basin will tend to vary, much as modern swamps vary in shape; sometimes being nearly round and again being long and narrow. These irregularities would seem to be due originally to irregularities of the ground, the swamps and coal being restricted to the hollows and lower land much as to-day. Where such a hollow was caused by the erosion of a stream or current the coal basin will be long, narrow and crooked. In another case the depression containing the coal was caused by a slight sinking of the earth's crust at that point. In this case the basin is apt to be more or less regular in shape and of considerable extent.

The following two figures may help to explain the difference in level between the "swamps" and "hill" as previously described. In

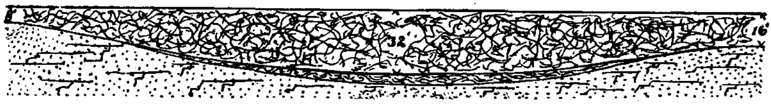

Fig. 5. Ideal section of a peat bog filling a rolling basin or hollow in the sandstone.

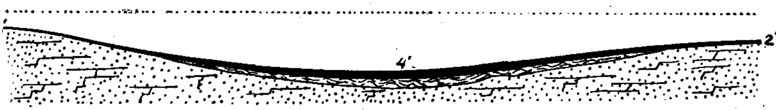

Fig. 6. Same, after submergence has allowed the laying down of sediments over it and its subsequent compression has taken place, allowing 1 foot of coal to be formed from each 8 feet of peat.

figure 5 a depression eroded from the sandstone is supposed to be filled to a level with vegetable matter, the depth at different points being indicated on the figure. Suppose now that subsidence allows the deposition of mud and other materials over this mass of vegetation; under the pressure of the superimposed beds, and through the loss of water and some of the gaseous matter shrinkage takes place, until finally the vegetable mass has been changed to coal, occupying say one-eighth of the original thickness, as shown in Fig. 6. It is evident that the originally level bed of vegetation will become saucer-shaped, the 32 ft. of matter at the center resulting in 4 ft. of coal in the "swamp," while the 8 ft. and 16 ft. of matter on the edges of the depression shrink to 1 and 2 ft. respectively, but due to the difference in the actual amount of shrinkage, the coal at these points is left at a much higher level than in the center of the basin.

49. UNCONFORMABILITY.—In the preceding paragraph mention was made of the coal basins having resulted in some cases in consequence of irregularities of the surface on which the coal was laid down. Such irregularities are usually good evidence that the surface in question had been lifted above the water level and become subject to erosion by rain, streams or sea water. If the elevation above water level is considerable, the rain and rivers may carve the surface into very noticeable hills and valleys, or it may only result in a gently rolling plain. The subsidence which follows may be sufficient to bring all the surface under water in the latter case and the coal would be laid down over all the area, as in Fig. 1; or it may in the former case only be sufficient to bring the valleys and lower ground under water. Deposits laid down in these hollows will then be restricted in extent to the submerged part of the area, and if seen in cross section will be observed as abutting against the old valley banks. In either case, such a condition is called unconformability. Coal laid down in such half-submerged depressions would, of course, occur in basins separated by areas containing no coal, and the coal would often be found to end rather abruptly against the valley bank. Such unconformabilities showing brief elevations of areas above water and their erosion by subaerial forces are common in the coal measures at many horizons. They serve to emphasize the restlessness, as it might be called, of the earth's surface during the coal measure age, to which attention has already been called by the frequent changes in the coal measure rocks in a vertical section. In this paragraph we are only concerned with unconformability in so far as it restricts the original laying down of the coal. In a following paragraph will be discussed the effect on the distribution of the coal of a land period and erosion following the laying down of the coal bed.

50. SPLITTING BEDS.—In some places the material between two coal beds thins out and the two beds come together, making, perhaps, one seam of good, workable thickness with only a thin parting, usually of fire-clay, running through it. Mining carried on in such double beds is liable to be limited by the separation of the component benches, the separated beds not paying to mine. Most of the thicker coal beds have partings of fire-clay indicating double beds or more, and such seams are liable to have the benches comprising them separate. In Indiana, the beds worked at Linton, Greene county, and at Cannelburg,

Daviess county, are notable examples, the coal beds worked at both these places dividing, and the parts are found to be 10 ft. to 15 ft. apart in a short distance.

51. Horsebacks.—Occasionally in a mine a ridge is encountered rising from the bottom and cutting the coal out. These are commonly known as "horsebacks." They appear to be due generally to currents which had deposited the material they carried in these ridges before the coal was laid down. True horsebacks, as thus defined, appear to be rare in Indiana. What are often termed "horsebacks" by the miners are here described under the head of "rolls."

52. Rock Partings.—As stated above, most of the thicker coal beds of this and other States are found to have fire-clay bands running through them, indicating a double bed. Differing somewhat from such partings are lenticular beds of shale, sandstone or other rocks which are sometimes found in a bed of coal. Such partings are usually brought in during the deposition of the coal material by water cur-

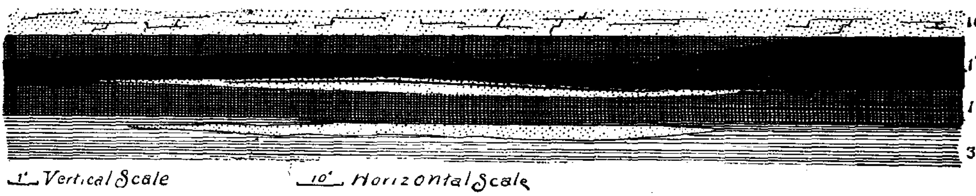

Fig. 7. Sketch showing sandstone parting in coal bed. From measurements in bluff near Shoals, Martin county.

rents, and, in contradistinction to the clay partings, they are usually quite local, being in the form of lenticular sheets which usually thin out within at the most a few hundred feet. They sometimes attain a thickness of several feet in the center of what is usually a solid bed of coal.

53. Rolls, of Contemporaneous Origin.—In general, rolls may be described as rock fillings of channels cut down into the coal. These channels may have been cut after the deposition of the coal bed and during a temporary land period, or they may have existed during the deposition of the coal, as open water channels. We are concerned here only with the latter. In large swamps to-day there commonly occur open water channels or even large irregular areas of open water. Open water channels are perhaps the more common, and, as a rule, they are kept open largely by the current of the water

flowing through them. In time, these channels tend to become filled up, sometimes with vegetable matter forming cannel coal, but often with mud or sand. In cases these may have filled up while the coal deposit was being formed on either side of them. Generally, however, it would seem that the filling had taken place just at the end of the coal forming period. The character of such a channel filling is shown by the following two figures. (See also Plate III, Fig. 1.)

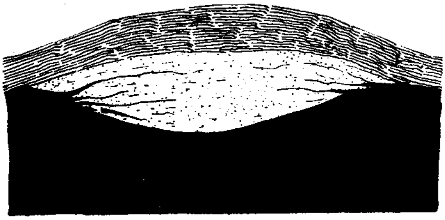

Fig. 8. Sketch of "roll" or sandstone filled channel which must have existed during or very soon after the deposition of the coal. From Crawford No. 1 mine in Parke county.

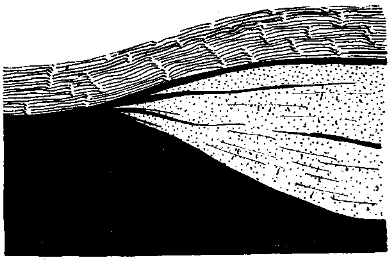

Fig. 9. Same, from old mine near Lafayette furnace, Clay county.

The two main characteristics as distinguishing such channels from somewhat similar channels to be described later (see paragraph 56) are: First—The usual roof of the coal extends over these channel fillings. Second—Lenticular sheets of coal extend out from the coal along the edge of the channel, especially from near the top, into the material of the channel filling, as shown in figures. These "streamers," or feeders, or fingers, as they are sometimes called, were evidently part of the loose vegetable matter of the main bed washed in sheets out into the partly filled channel.

In general, it would seem that when the sinking had become temporarily rapid so as to stop the deposition of coal material, and the submergence had allowed sand or mud carrying currents to flow all over the recently laid down vegetable mass, the sand or mud naturally lodged in the depressions of these old current channels, filling them, the new currents sweeping some of the vegetable matter in at the same time.

These conditions might continue until a similar deposit of sand or mud had been laid down over all the area or, what is more common, the sinking continues, bringing in deeper water, feebler currents and a change in the material carried by them from sand to fine mud, as in Figs. 8 and 9, where both the coal and old channel filling are covered by shale.

A third fairly constant characteristic of such a filling is shown in Figs. 8 and 9, where it will be observed that the roof bends up over the channel filling; also that some of the thin sheets of coal in the filling bend upward instead of being flat or bending downward, as they must have at first. The explanation would seem to be that the coal bed had only been partly compressed when the roof was laid down on it and when the thin sheets of coal were washed out, and, due to the difference of material, the coal had afterward suffered compression more than the harder filling of the channel. Three other points sometimes observed would seem to favor that explanation. It is frequently found that the coal on either side of such a filling is a little thicker than the bed is elsewhere, suggesting that the coal has been squeezed out from under the filling. Again, where the under clay is soft, it is sometimes found that the coal below the filling has been forced down into the clay several inches. Again, below and close to such a filling the coal is usually much disturbed, or "troubled," as the miner would say, such coal not mining in large blocks or lumps, but largely going into screened coal. (See Fig. 17.)

From the practical standpoint these channel fillings, or "rolls," as they are commonly called, affect mining principally in: First—Cutting out the coal; sometimes they extend to the bottom of the bed; and, second, in rendering the roof bad and unsafe, as they are liable to separate from the regular roof at some of the coal partings and come down in great masses, often with fatal results. They are sometimes V-shaped, but more often broadly U-shaped, or flatter still, as shown in Fig. 1 of Plate III.

Section 2. Irregularities Due to Subsequent Erosion.

The lateral extent and in places the vertical extent or thickness of the coal have been largely governed by the factor of subsequent erosion. This may be divided according to time into—

1. The erosion which has resulted in the present shape of the ground.
2. Preglacial erosion, now hidden.
3. Subsequent erosions during the laying down of the coal measures.

54. Recent Erosion, or the Erosion Which Has Resulted in the Present Shape of the Ground.—The question of during just what ages since the coal measures this erosion has been in progress is an interesting one, but we are principally concerned now with the final result. If we study any single coal bed in Indiana we find,

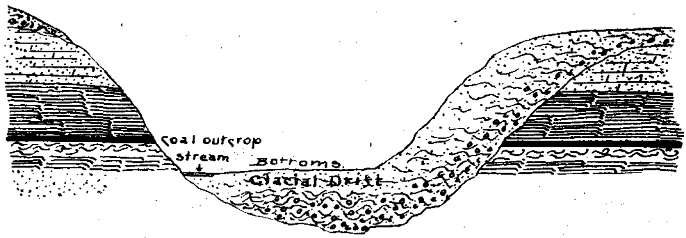

Fig. 10. Sketch to show removal of coal across recent stream valley. Also showing why outcrops are often found on one side of a valley and not on the other.

as we go eastward, it tends to get nearer and nearer the surface. Finally it outcrops in the bottoms of creeks and can be worked by slopes and drifts; still going eastward it is found higher and higher in the banks or adjacent hills, until finally it crops out in the side of a hill with a rise that would carry it over any hills to the east. At its most eastern outcrop it is often or usually just as thick as to the west. Evidently the coal bed formerly extended an unknown distance further east, but has been washed away in the slow lowering of the land during past ages by the streams and their tributaries. In this way untold millions of tons of Indiana coal have been washed away and the process is still going on, as is evidenced by the "float" coal found in creek bottoms where the coal is being washed from some outcrop. This is shown in the cross sections on the large sheets; refer also to Part II, under structure of Indiana coal field.

In addition to the removal of large bodies of coal due to the eastward rise of the coal and general erosion, and as part of that same process, is the removal of large quantities of coal by the streams in cutting out their present channels.

Thus, with conditions as in Fig. 10, it is quite generally appreciated that the coal formerly extended across the valley, but has been removed by the stream in cutting its channel, but often where conditions favor an exposure on one side of the valley and not on the other, as in the figure, the unexposed side of the valley is neglected for many years after the exposed side is all worked out under the impression that no coal exists there. Where good, workable coal is exposed along one side of a valley, it should be assumed to be on the other side until drillings made well back from the bank have shown it is not there. The reason why coal is often found on one side of a stream and is apparently wanting on the other side will be given further on.

55. Preglacial Erosion.—As will be described more fully further on, most of Indiana, in common with a large area in the northern part of the United States, was, at a comparatively recent period, geolog-

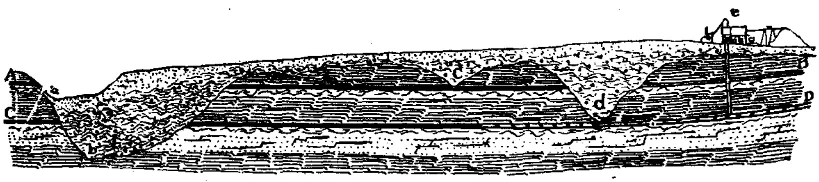

Fig. 11. Sketch showing present land surface and underlying preglacial surface, and the effect of the latter on the distribution of the coal. At (a) is represented a recent water channel. At (b) is its preglacial predecessor, larger and deeper. The old channel is seen to have cut out large areas of both coal beds. At (c) is a small channel only reaching the upper bed. At (d) is a deep channel, not revealed on the surface, which cuts out a considerable belt of the upper bed and just cuts into the lower bed, making there a "clay roll." It is easy to see how a drilling at (d) might lead to the conclusion that there was no coal in that district.

ically speaking, invaded by one or more great ice sheets or glaciers. These pushed their way from the north southward across the State, scraping off great quantities of loose earth and soft rock, and then, as they retreated, redeposited this material so as to practically fill up all the valleys and former irregularities, frequently or generally leaving little or no trace of the old valleys. In this way it frequently happens that a stretch of country apparently level and unbroken was before the Ice Age a rugged country with broad, deep valleys from across which large amounts of coal have been removed. Fig. 11 shows such a valley at *d*, a smaller one at *c* and a larger one at *b*. In the latter case a recent stream is beginning to clear out the old channel. In Fig. 10 is a somewhat similar case, only that the stream has progressed farther in the clearing out process. In some cases these hidden valleys can be traced for considerable distances, being revealed by drilling and mining operations. The filling is usually found to consist of clay and sand with boulders or pebbles, gravel, sticks, parts of trees, sometimes chunks of coal, etc.

These preglacial valleys, where hidden, may render large tracts of what on the surface appears to be valuable coal lands, practically worthless. In the Indiana coal field the preglacial valleys were both deeper and broader than the present valleys, so that the coal cut out and removed by the preglacial drainage far exceeded that removed by the present streams.

56. Erosion of Carboniferous Age.—The channels of streams of carboniferous age resemble somewhat the hidden channels of preglacial age, except that the material filling them is a thoroughly consolidated sandstone or shale, more usually the former. The evidence is abundant that at numerous times during the laying down of the coal beds and associated rocks, elevation brought the recently deposited coal beds and the other rocks above the water level, and streams eroded channels for themselves, sometimes just into the coal, sometimes entirely through it. The following figure shows a characteristic channel of this description. These channel fillings are usually known as rolls.

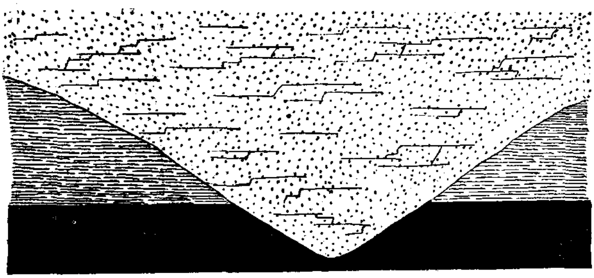

Fig. 12. Carboniferous erosion in coal. Buell mine, Sullivan county

In many cases, instead of simply cutting out a narrow channel, as in Fig. 12, broad areas will be slightly eroded, the normal roof being removed and the top of the coal being more or less carried away. The filling of these channels or broad washes is usually sandstone. It will generally be noted that where the roof of a certain bed of coal is normally shale, if at any point the shale roof seems to thin out and a sandstone comes down on the coal, the coal is not as thick as elsewhere, and often the sandstone roof is somewhat wavy, as though the erosion had been irregular. Fig. 13 will help to show the conditions. In these cases a broad current would seem to be the agent rather than a stream.

Fig. 13. Broad wash erosion of carboniferous age.

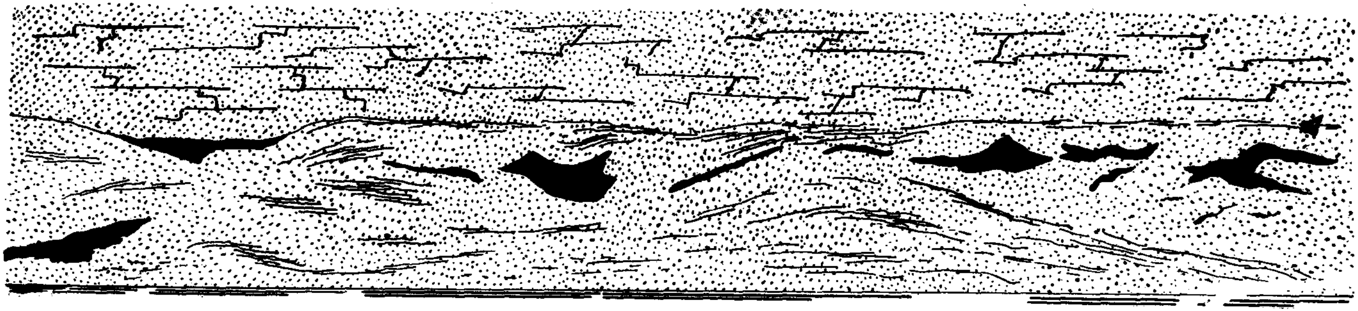

Fig. 14. Redeposition of parts of eroded coal bed. From bluff on Sand creek, Parke county. One inch equals seven feet.

In some cases the erosion has been more pronounced and only traces of the coal bed are left. In other cases none of the coal left appears to be in its original position, but appears as scattered masses and fragments probably at some distance from where first deposited. Fig. 14, from a long bluff on Sand creek, in Parke county, shows well such a redeposition of some of the coal.

Section 3. Irregularities Due to Movements of the Earth's Crust.

These show themselves as, first, lack of horizontality of the coal and accompanying beds; and, second, as breaks or faults of the strata, with accompanying phenomena.

57. Dip.—It is the exception rather than the rule to find coal beds lying horizontally even for short distances. To a certain extent this is an advantage, as it allows a mine to be drained. This inclination from the horizontal is called the "dip" of the rocks, and where small is measured as so many feet to the mile, or, if somewhat larger, as so many feet to the hundred feet. If still higher it is usual to give the dip in degrees. Coal beds usually have a major and a minor dip; that is, considering a coal bed over a large area it may gradually be found at lower and lower levels in a certain direction; though examined at any point the dip may be found to be in any direction. In Indiana, the major dip over most of the field is a little south of west. In this case the major dip seems to be the result of slow subsidence of the earth's crust affecting most of Illinois, Indiana and Kentucky. (See Part II.) If the minor dips be examined it is found that as a rule the rocks dip away from lines which might be drawn, and often toward other lines, thus forming long arches, or anticlines as they are technically known, and long troughs or synclines. A line showing the highest part of the arch at different points is called the axis of the anticline, and correspondingly is used the term—axis of the syncline. These anticlines and synclines seem to be wrinkles in the earth's crust produced during the progress of the broader earth movements.

In Indiana the major dip will range from 3 to 100 ft. per mile, while the minor dips may be 100 or 200 ft. in a mile, or, for short distances, 30 to 40 ft. in 100; or, for a space of a very few feet, even higher. The dip of the coal affects the practical operation of mining principally in connection with drainage and haulage. In countries where the rocky strata have been highly folded so as to more or less nearly "stand on end" the coal beds are of course similarly inclined and require entirely different methods of mining. The anthracite coal beds of Pennsylvania are illustrations of highly inclined or "dipping beds."

58. FAULTS. In the report on Sullivan county made in 1871 by Mr. Collett, he writes as follows:* "An interesting feature of this mine (Badger Bros.' shaft) was the discovery of a *vertical* dyke or wall of intrusive clay, one foot wide, running a little east of north. This is the only fault, though here only a separation, that I have met with in the coals of Indiana," etc.

In a general review of the geology of the State made by Mr. Cox, in his last report published in 1879, he says:† "Here the elements concerned in the building up of strata leave no trace of violent cataclysms, and the rocks presented to view lie regularly bedded at an inclination or dip to the westward and northward, so gentle that its existence can only be made known by observations extended to points that are far distant from one another. *Not a single true fault*,‡ or upward or downward break and displacement of the strata has yet been discovered."

In view of such statements repeated by the members of the earlier surveys, it has seemed well to give more than a passing mention to the subject of faults, etc. Instead of the entire absence of faults and similar disturbances which we have been led to expect by the early reports, the members of the present survey found true faults a very common phenomena, in some districts hardly a mine being free from them and ranging in downthrow from a few inches to forty feet.

59. FAULTS, NORMAL.—The term fault is often used by the miners and others to describe any kind of an irregularity in the coal, especially of places where the coal is more or less cut off, whether this be by a true fault, an erosion channel or from other cause. Strictly, a fault is a fracture or break extending across the strata accompanied by a greater or less displacement along the line of fracture. Faults are usually classed as normal or reversed faults. The normal fault is the more common in Indiana, as elsewhere. In the normal fault the action seems to have been accompanied by tension and it will be noted that if the displaced strata be brought to the same level a separation has taken place. This is shown in Plate II. In the reversed fault compression has acted forcing the strata together endways and usually causing more or less of an overlapping of the ends of the strata on

*1871, Sec. Ann. Rep., Geol. Surv. of Ind., p. 205.
†1879, 8th, 9th and 10th Ann. Rep., Geol. Surv. of Ind., p. 3.
‡Italics mine.—G. H. A.

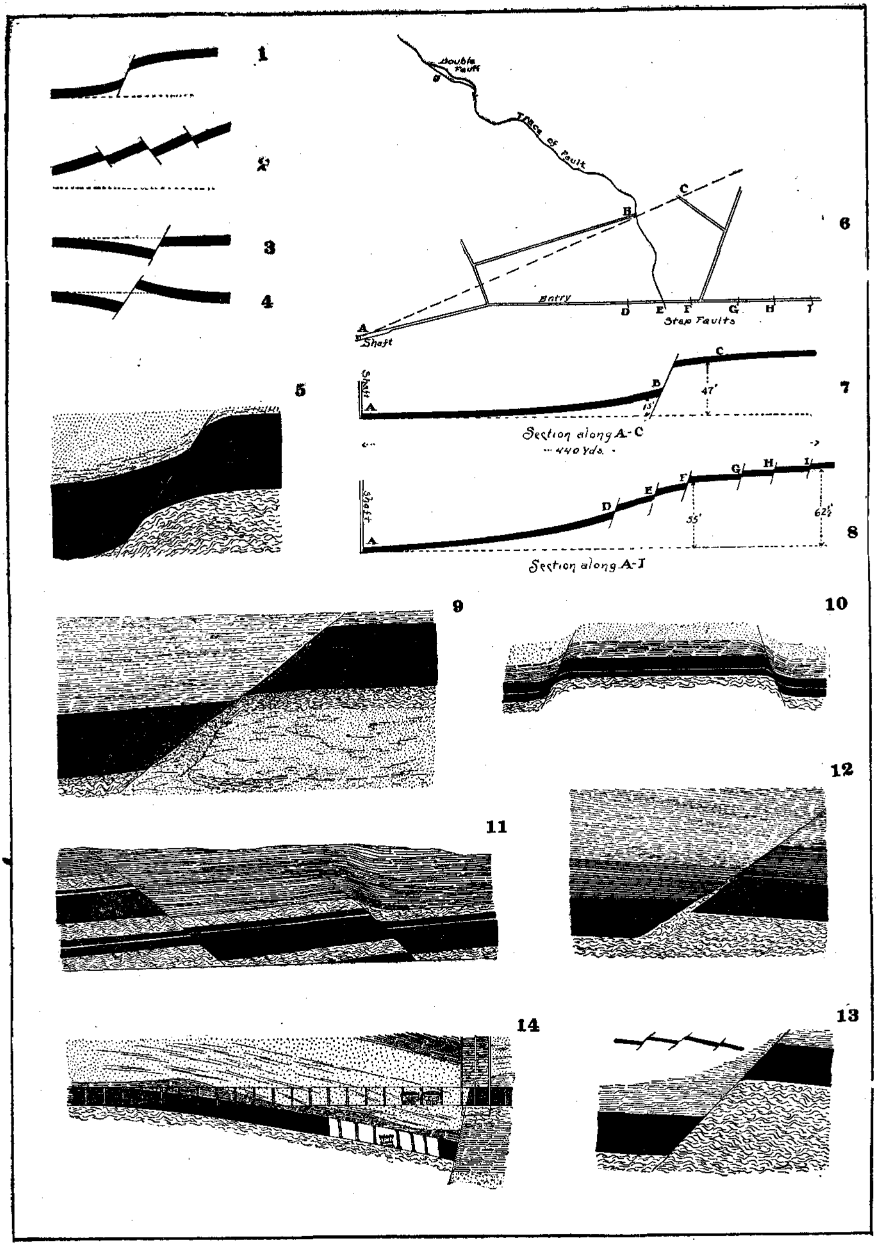

Plate II. Typical Normal Faults.

Fig. 1. Type of monoclinal fault. See Figs. 5 to 10 inclusive.
Fig. 2. Broken arch type of fault. See Figs. 11 to 13 inclusive.
Fig. 3. Type of fault shown in Fig. 14.
Fig. 4. Type of fault shown in Fig. 2 of Plate III.
Fig. 5. Fault in Fairview mine, Clay county.
Figs. 6–8. Fault in B. B. C. Co.'s No. 10 shaft. Map and section.
Fig. 9. Fault on Otter creek, three miles north of Brazil. From photo.
Fig. 10. Double fault in Peerless mine, Vigo county.
Fig. 11. Double fault on Big Vermillion river, near Hanging Rock.
Fig. 12. Fault on north fork Otter creek, near Coal Bluff, Vigo county.
Fig. 13. One of series of faults in Fairview mine.
Fig. 14. Fault crossing shaft in Jackson mine, Clay county.

one side of the break over the ends of the corresponding strata on the other side, as in Figs. 12 and 13 of Plate III.

A normal fault may result in a sharp, clean break, with a displacement of from a few inches up. In the coal fields of Indiana vertical displacements of 30 to 40 ft. are as large as have been observed. Figs. 4, 7, 9 of Plate II are typical of simple normal faults such as are common in the coal field of Indiana. Such faults are often traceable for long distances, especially those of large downthrow or displacement. In some cases the same fault has been found in adjacent mines. Occasionally the displacement takes place by a series of small displacements known as a double fault, as in Fig. 11 of Plate II, or as a step fault, as in Fig. 8 of Plate II. Figs. 6, 7 and 8 of Plate II show the case of a simple fault of 32 ft. vertical downthrow breaking up into a series of small faults. At *j* in Fig. 6 the large fault is for a short distance broken horizontally with a horizontal displacement which runs out at either end. The irregularity of the line of fault horizontally is well shown in the same figure taken from the mine map of their shaft No. 10, by permission of the Brazil Block Coal Company.

In many cases the line of fracture has not been a straight line, as in the figures above referred to, but seems to have been irregular, and in some cases the movement seems to have been to some extent horizontal. As the spaces have usually been filled with clay, they are commonly known as clay veins and will be discussed under that head.

Faults of this type are sometimes known as gravity faults, as gravity is the principal factor in their production. It will be noted also that, as a rule, the line of fracture is nearly vertical, due to the fact that the line of displacement has usually followed a joint plane, which, in such a region as this, tends to be vertical. They may be assigned to two causes: *First, the uneven settling of the whole basin during the laying down of the coal measures or afterwards.* An examination at distances apart of corresponding coals at different points shows this settling to have been very irregular. The field contains many instances of where at one point two beds are fully 50 to 100 ft. apart, while a few miles away they may be only 5 to 10 ft. apart or less. At the first point, then, the strata have sunk perhaps 50 to 75 ft. more than at the second point, since the lying down of the lower coal. This differential movement may tend to produce straining in the strata between the two places, which is relieved either by bending or shearing of the rocks. A second cause which may account for some of the smaller faults is suggested to be the irregular settling over basin-shaped bodies of coal, and the interruption which such settling encounters along the lines of channels which have been cut in the coal and filled with sandstone. This is merely suggested as a possible cause for some of the small faults.

A second type of fault may be distinguished as having its "hade," or direction of dip of the plane of fracture, in an opposite direction from the general dip of the strata; see Fig. 2 of Plate II. Figs. 11, 12 and 13 of Plate II are of this type. Such faults are common in the plateau district of the western States.

These faults, taken as a whole, do not appear to have any uniformity in the direction of downthrow or of strike. However, if only the larger faults be considered, a majority of them trend between northwest and northeast and have the downthrow to the west. There are so many notable exceptions that it cannot be considered as a rule. Thus, in Martin county, from Shoals westward, the dip is nearly everywhere observed to be strongly to the west, yet so many faults with the downthrow to the east occur in that region that the strata are higher five miles west of Shoals than at Shoals.

Figs. 14 of Plate II and 2 of Plate III illustrate two other types of faults as shown in Figs. 3 and 4 of Plate II. The difference between the faults of the first two types and those of the last two are very well shown in the effect on the driving of entries in the mines. Thus a six-foot fault of the first type necessitates driving the entry up or down until it is at least 6 ft. above or below its old level, according as the fault is approached. A six-foot fault of the third type can be passed with little or no change of level in the entry.

60. Faults, Reversed.—Reversed faults that could be recognized were not found abundantly, though it is suspected that a large part of the faults described as clay veins are really of the character of reversed faults. The writer had the opportunity to examine and sketch only one notable fault of this kind of which the character was unmistakable. This was in Columbia No. 4 mine of the Columbia Coal Company in Clay county. In this case the compression has been great enough to force the lower block coal bed up a diagonal shearing plane an unknown distance above the upper block coal bed lying 20 ft. above it; see Fig. 13, Plate III. In this case the whole field for several miles shows the result of the compression in many ways as described in Part III of this report. Of the numerous faults of this type described to the writer, but which could not be examined, the one shown in Fig. 15 from the Eaton mine in Sullivan county is selected for presentation. The figure is from a sketch by Mr. Winterbottom, and makes no pretext to be reliable in detail. The coal attains a local

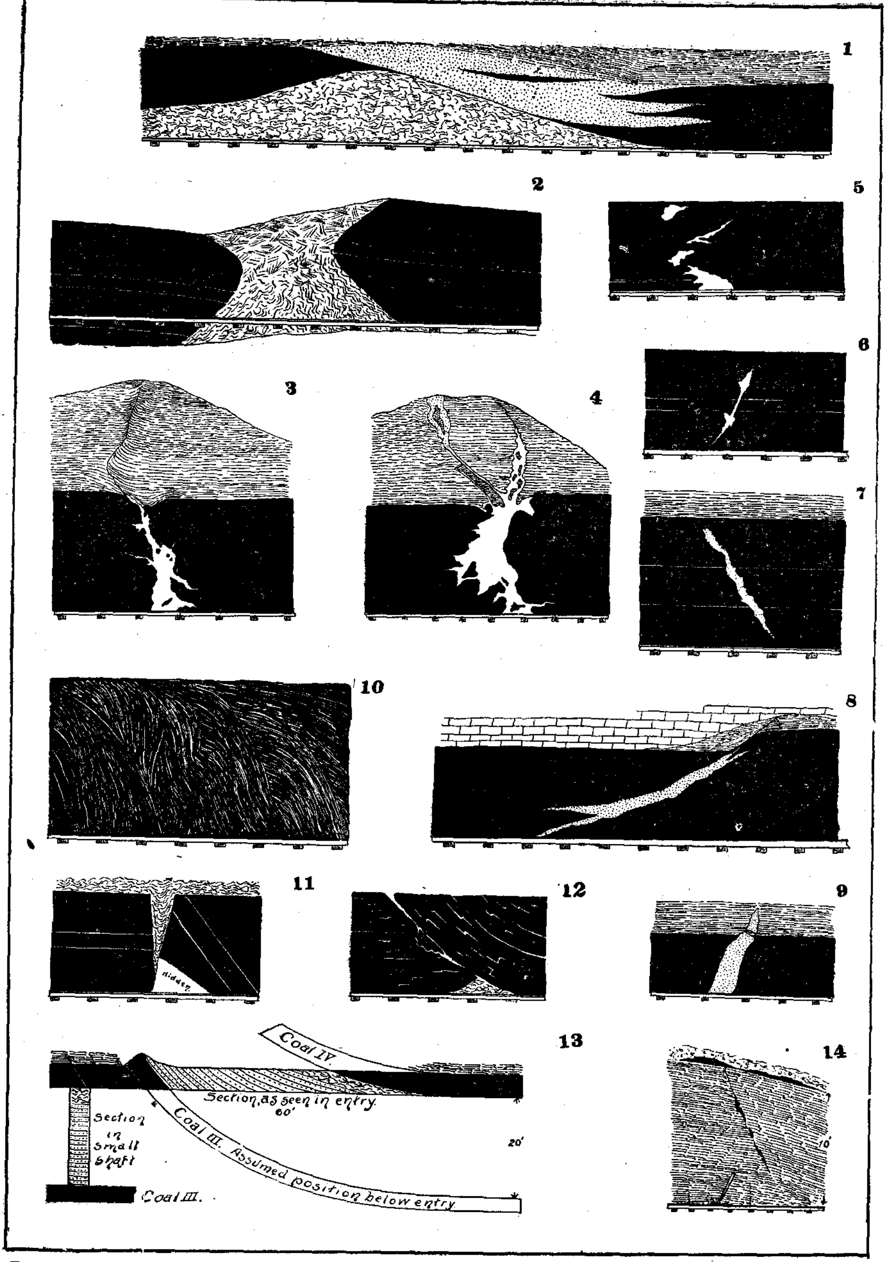

Plate III. Irregularities due to faulting; clay, sandstone and coal veins; overthrust faults and crushed structure.

Fig. 1. Combined fault and "roll," Monarch mine, Clay county.
Fig. 2. Fault of type 4, Dugger mine, Sullivan county.
Figs. 3-4. Clay veins resulting from faults. Parke County Coal Co.'s No. 6 shaft, Parke county.
Fig. 5. Clay in old fault plane, Wimsett mine, Vermillion county.
Fig. 6. Clay vein, Dugger mine, ten feet from and running parallel to a large fault.
Fig. 7. Sandstone vein, Ray mine, Vigo county. Displacement shown in another entry.
Fig. 8. Sandstone vein, Mecca No. 1 mine, Parke county.
Fig. 9. Sandstone vein, Brazil Block Coal Co.'s No. 8 mine, Clay county.
Fig. 10. Showing structure of coal bed thickened to nearly four times normal thickness by lateral pressure, in region of overthrust faults, Columbia No. 3 mine, Clay county.

thickness of 12 ft. In this case it would seem that the cause might be of a local nature and due to the coal being forced out laterally from under the "rock roll" shown at the left.

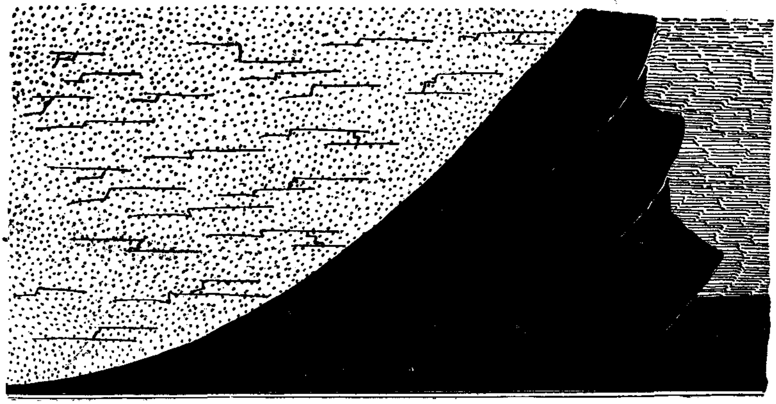

Fig. 15. Thickened coal bed in Eaton mine, from rough sketch by Mr. Winterbottom. Coal in shaft 12 feet thick. Regular thickness of bed, 3 feet.

61. CLAY VEINS.—"Clay veins" are abundantly found in the mines of Indiana. They are usually very irregular bands of clay extending more or less vertically through the coal and accompanying strata. In some cases they are clearly the result of faulting, as in Figs. 3 and 4, Plate III, or, as in the case of the vein shown in Fig.6, Plate III, their association with neighboring faults show that they are due to the action of the same forces. In some cases, as in Fig. 7, Plate III, the vein shows no displacement in one part of a mine, but may show a noticeable downthrow in some other part of the mine. While in a few places the clay seems simply to fill the space made by the separation of the rocks on either side of the line of faulting; in most cases the coal and rock close to the fault on either side seem to have been broken up or even reduced to a fine state, and when the clay was forced up through this mass it extended out into it, following lines of least resistance, and catching up masses of it in the main clay body. This is shown in Figs. 3 and 4 of Plate III. In some cases the clay vein does not appear to extend clear through the coal, as in Fig. 6, Plate III, or the clay may appear in irregular detached masses in the coal, as in Fig. 5, Plate III. In either case the clay appears to be entirely separated from any source of supply. Minute examination will, however, usually reveal traces of the break having been much

more extensive than it appears; in other words, the break closed up again after being partly filled with clay. In the cases illustrated by Fig. 2, Plate III, the vein is only in part clay, the upper part consisting of broken-up shale. As might be expected, this shale forms a treacherous roof.

62. Coal Veins, Sandstone Veins, "Rock Spars."—Of somewhat similar appearance to the clay veins are what are commonly known in the mines as "rock spars." These veins are characterized by a filling of sandstone, coal or other material than clay, sandstone

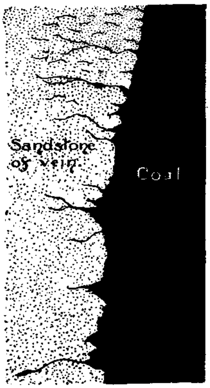

Fig. 16. Contact between coal and sandstone vein. (Natural size.)

being most commonly met with, and by more regular bounding faces. In the case of most—if, indeed, not all—of the clay veins the plastic clay seems to have been forced into its present position by pressure. In the case of the sandstone and coal veins, however, the filling material seems, in many cases, to have been carried into surface crevices by water or wind. Of the figures given, this is best shown by Fig. 14 of Plate III, where the coal vein seen in the entry (see Fig. 3) can be traced up to an old erosion level, where an irregular layer of coal, quite clearly washed in, lies over the top of the crevice containing the coal. As with many of the clay veins, the crevice at the line of the section has closed while only partly filled. Sandstone veins or "rock spars" were not met with abundantly, though occasionally single mines or small districts have encountered a great many. In other cases sandstone and shale make up part of the filling of fault veins, as in Figs. 1 and 2, Plate III, or all of the vein, as in Figs. 7 or 8, Plate III, in the latter case the fault structure being shown in another part of the mine. In the case of Fig. 9, Plate III, the cause is obscure. As usual the sandstone is very hard and closely knit with the coal along their line of contact, as shown in Fig. 16.

63. Thickened Beds.—In some places, usually in regions of reversed faults, the pressure has, in places, instead of breaking the strata and shoving them over each other, simply crushed the coal horizontally, with the result of increasing greatly its apparent thickness.

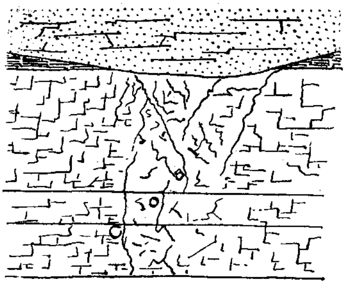

Fig. 17. A "trouble," showing effect on structure of coal from slight squeezing under sandstone roll, Fortner mine, Clay county.

Thus a 3 or 4 ft. bed may locally be increased to 10 or 12 ft. Fig. 10, Plate III, shows the structure of a portion of such a thickened bed in the Columbia No. 3 mine of the Columbia Coal Co., Clay county. Fig. 17 shows the appearance of a "trouble," as the miners call it, where the regular structure of the coal is destroyed by pressure due to any of the causes previously discussed.

V. GEOLOGICAL AND GEOGRAPHICAL DISTRIBUTION OF COAL.

Coal deposits are widely distributed over the earth, the largest deposits occurring in the United States, Great Britain and China.

64. Along the Atlantic Border there is an area of 18,000 square miles of coal in Nova Scotia and New Brunswick. In Rhode Island is a small area of 500 square miles. Other small areas are found to the south, notably in Virginia and North Carolina.

65. Appalachian Coal Field.—The main supply of coal in the United States is obtained from the Mississippi valley. Four coal fields occur in this area. Of these the most important is the one known as the Appalachian coal field, including the coal of Pennsylvania, Ohio, West Virginia, eastern Kentucky, western Virginia, Tennessee and

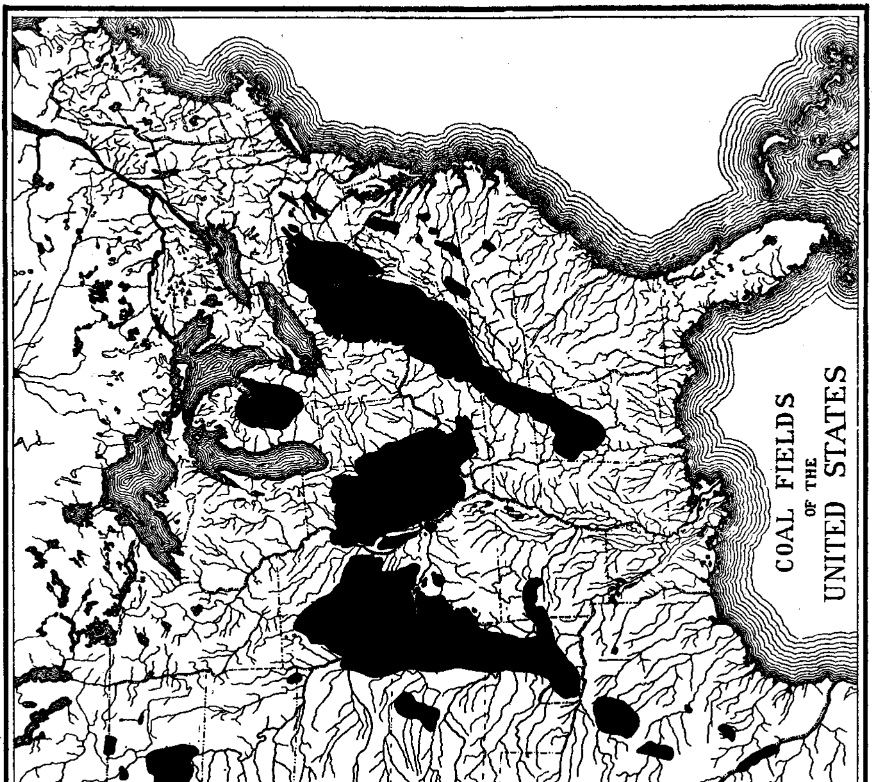

PLATE IV.

Alabama, and covering an area some 700 miles long by nearly 100 miles wide, or nearly 60,000 square miles. It occupies a long trough lying between the Appalachian mountains and the Cincinnati-Nashville-Ouachita arch, the rocks on either side dipping towards the center of this trough.

66. IN MICHIGAN occurs a small isolated basin having an area of 6,700 square miles, or about equal to the area of the coal field of Indiana. It is, however, a very shallow basin, and a considerable part of the area is made up of the lowest part of the coal measures which, as in Indiana and elsewhere, is almost barren of coal. One or two workable basins are mined on a limited scale.

In the center of the Mississippi valley occurs the great interior coal field, often divided into the eastern and western fields.

67. THE EASTERN INTERIOR COAL FIELD, or, as it is sometimes known, the Illinois Coal Field, covers an area of 47,000 square miles, and comprises central and southern Illinois, southwestern Indiana and northwestern Kentucky. It is with this field that we shall be principally concerned in this paper. The coal occurs in an elliptical basin with a center in Illinois, towards which the rocks of the basin slope. This basin will be described more in detail in Part II.

68. THE WESTERN INTERIOR COAL FIELD is only separated from the eastern by the erosion of the Mississippi river, which runs along an arch. This area of some 78,000 square miles includes southern Iowa, northwestern Missouri, the eastern edge of Nebraska, Kansas and Indian Territory, western Arkansas and, as shown on the map, extending in a tongue down into Texas.

69. IN THE WESTERN HALF OF THE UNITED STATES coal occurs in scattered patches over an aggregate area of many thousand square miles and is found in all the Western and Pacific coast States and Territories. These deposits also occur in British Columbia and western Canada. Some coal occurs in Cuba, Peru and at other points south of the United States.

70. IN EUROPE, Great Britain has 12,000 square miles, Spain 4,000 square miles, France 2,000 square miles, Belgium 518 square miles, while some coal is found in Germany and Sweden.

71. IN ASIA workable coal beds occur in Japan, China, and India, also in Australia and New Zealand, and the Philippine Islands.

72. COALS OF DIFFERENT AGES.—It has been found, however, that these coals were not all deposited at the same time. By studying the order in which the layers of rock lie one above the other, and by using the fact that long study has proven, that the life of the world has steadily changed from age to age, geologists have been able to work out an historical order for all the rocks of the world. And by means of the fossils and plant remains enclosed in the rocks, they are able to decide the relative position or time of laying down of any chosen group of rocks.

In this way it has been found that the larger part of the coal of the world was laid down at about the same time, and from that fact they have called that age the Carboniferous or carbon-bearing age, or shortly the Carbonic age. In this study they have shown that the coal of central and eastern North America was laid down several ages, representing probably many million years, before the coal of western America. They have been able to show that the coals which are hardest and heaviest and contain the largest percentage of carbon and the smallest percentage of the volatile gases were deposited the longest time ago, as a general rule.

The following table shows the names given to the successive geological time periods, the kind of coal most characteristic of each and the places where the coal of that age occurs:

TABLE SHOWING GEOLOGICAL DISTRIBUTION OF COAL.

Geological Ages.	Characteristic Coal.	Where Found.
Quaternary	Peat	Wide spread.
Tertiary	Lignite or brown coal	Wide spread, especially in Vermont, Texas, California, Germany, the Philippine Islands, and many Western States.
Cretaceous	Bituminous	Colorado, New Mexico, Wyoming, North and South Dakota, Montana, Washington, Oregon, British Columbia, Canada north of Montreal, New Zealand, Germany.
Jurassic	Bituminous	A little in a few places.
Triassic	Bituminous	Virginia, North Carolina, Australia and India.
Carbonic	Bituminous Anthracite	Eastern America, Great Britain, Spain, France, Germany, Russia, Belgium, Japan, China, India, Australia.
Devonian Silurian Cambrian		Traces of coal in a few places.

One of the main facts of value in the above table is in its showing what experience has proven, that no coal of commercial value has ever been found in rocks underlying the carboniferous. And it will be further of interest to note that coal is found only in part of the Carboniferous. Thus the Carboniferous has been divided into:

Permian—
  Limestones, sandstones and shales.
Carboniferous or Pennsylvanian Series—
  Shales, sandstones, limestones, COAL and iron ore.
Lower or Eo-Carboniferous or Mississippian Series—
  Limestones, sandstones and shale (limestone predominating in Indiana).

As shown, coal of commercial value is practically restricted to the middle division. And as the lower part of the middle division is usually a very thick sandstone, often gritty, or even approaching a conglomerate with which are usually associated only thin and unimportant coal beds, the middle division is often divided up into

The coal measures,
The millstone grit.

The commercially valuable coal of Indiana is practically restricted to that division of the Carbonic rocks known as the coal measures.