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# ORIGIN OF THE PENNSYLVANIA ANTHRACITE

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## CONTENTS

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## Introduction.

Tables of analyses of coals from the Pennsylvania bituminous areas show that the proportion of volatile combustible matter decreases toward the east, though the rate of decrease is not regular and differs in the different beds. The decrease is even more marked in that portion of the state lying eastward from the bituminous areas, for there one finds the passage from semi-bituminous to the hard dry anthracite of the Middle fields.

## Pennsylvania Coal Areas.

### *General Extent.*

A general knowledge of the features and relations of the several coal fields or geologic basins in Pennsylvania, as well as of their extensions toward the south, is absolutely essential to an intelligent discussion of the cause of the decrease in volatile. The portions of these basins or areas lying within Pennsylvania was described by Professor H. D. Rogers in his final report on the geology of the state, to which the reader is referred for details beyond those given here. It should be remembered in this connection that while the general trend of the Appalachian chain is from north-northeast to south-southwest, yet the system describes many curves, so that in some portions of its course the trend is almost east and west, a fact exceedingly important in its bearing upon the value of comparisons made along certain lines.

Immediately beyond the South mountain or Blue ridge is the Great valley which, with many names, extends almost unbroken from New England to Alabama and is bounded on its northwesterly side by a monoclinal ridge known in Pennsylvania as Kittatinny or North mountain, but by many names in its course through Virginia.

### *GEOLOGIC STRUCTURE.*

The first coal-bearing area is the somewhat complex region lying between the Kittatinny and the Alleghany mountain, the latter an irregular ridge traceable from Luzerne county southward almost to the Maryland line, where it becomes an anticlinal with the Cumberland or Potomac coal field at its easterly foot. In a general way, disturbance was much greater within the valley than within this second area, for Cambrian and Silurian rocks prevail in the former, whereas those rocks are deeply buried in much of the latter. In its northward extent, the latter is, comparatively speaking, a broad, gently folded area, in which rocks older than the Devonian are rarely shown and the Coal Measures have been preserved in deep synclinals known as the anthracite fields. Southward the plication is greater; new and abrupt folds make their appearance, so that in the central and other counties of Pennsylvania almost to the Maryland line, the Lower Silurian is present in broad spaces and Upper Silurian is a striking feature of the scenery. Still further southward, faults, for the most part insignificant in this portion of Pennsylvania, become more and more numerous until in southwest Virginia they are the characteristic structural features.

### *ANTHRACITE STRIP.*

As the result of this increasing plication southward, the Southern and possibly the Middle anthracite fields have no representatives in the southern counties of Pennsylvania, but the synclinal of Licking mountain, in Fulton county, just fails to hold the Coal Measures; it is where the representative of the Southern field should be. The Northern or Wyoming-Wilkesbarre field is represented in Huntingdon, Fulton and Bedford counties by the Broad Top coal-field, while still further southwestward and almost 20 miles nearer the Alleghany mountain is the

Savage mountain synclinal, holding the Cumberland coal field of Maryland and Virginia. These two fields are in such relation geographically to the Alleghany mountain on the one side and to the North or Kittatinny mountain on the other, that either one of them may be taken as practically representative of the Northern anthracite field.

*BITUMINOUS BASINS.*

Beyond the Alleghany mountain one comes to the bituminous coal basins, which are sharply defined in the southern portion of Pennsylvania, but become less and less defined northward, and soon disappear southward.

The first basin beyond the Alleghany mountain has the bold axis of Laurel hill as its western boundary in West Virginia and southern Pennsylvania, embracing Somerset and Cambria counties in the best defined portion. Northward the trough, ascending, becomes shallower, but it can be traced without difficulty to the New York line, holding small patches of coal in Lycoming, Sullivan and Wyoming, the latter two being in what is termed the Loyalsock coal-field. It forms part of the Mahoopeny mountain in the Loyalsock area, and is part of the Alleghany mountain in Lycoming, Centre and Clinton counties.

The second basin is well known in southern Pennsylvania as the Ligonier valley, bounded for more than 100 miles in Pennsylvania by the anticlinals forming Laurel and Chestnut hills or mountains. At the south it becomes well defined first at not far beyond the Baltimore and Ohio railroad in West Virginia, and embraces parts of Harrison, Taylor and Preston counties. It enters Pennsylvania in eastern Fayette, and continues through Fayette, Westmoreland, Indiana, Clearfield, Lycoming and Bradford counties, its last areas of coal being the Ralston in Lycoming and the Barclay in Bradford. Its coal-field ceases to be continuous beyond the Susquehanna river, which crosses it at Karthaus.

The third basin is a broad area, consisting, along the Pennsylvania railroad, of three sub-basins, which are well defined in Westmoreland county; but the basin practically becomes one at a short distance south from the Pennsylvania line in West Virginia. It embraces, in Pennsylvania, the Coke basin of Connellsville, the Greensburg basin of Westmoreland county and the Lisbon basin of Greene, Fayette, Westmoreland and Indiana. Northward, however, these sub-basins disappear, the troughs become very shallow, and at length only isolated tracts of coal remain, as at Blossburg, in Tioga county, on the narrow synclinal ridge crossing into Bradford county.

The fourth basin is bounded by a bold anticlinal crossing the Ohio river just below Pittsburg. It embraces, north from that river, parts of

Armstrong, Jefferson, Elk, Cameron, Potter and Tioga counties, the most northerly exposure of coal being on Driftwood creek in the last-named county.

The fifth basin is bounded at the west by the Brady's Bend anticlinal, which is persistent to the northern line of the state. It embraces portions of Allegheny, Armstrong and Clarion counties, and crosses southeast McKean into Potter county, where the Coal Measures appear in small areas of insignificant value.

The sixth basin embraces the rest of northwest Pennsylvania, and may be regarded as including all that remains of the bituminous region in Pennsylvania and Ohio, for beyond the Brady's Bend axis the folds are petty and without great extent along the strike.

### *RELATION TO MARYLAND AND VIRGINIA COAL AREAS.*

Practically, the last four basins become one at the south. Certainly the third and fourth may be regarded as one at but a little way southward beyond the West Virginia line, while at 50 miles south from the Baltimore and Ohio railroad, in that state, the first and second have coalesced with each other and with the third, owing to the steady depression of the anticlinals in that direction. So, then, what are the conditions in these basins?

Along a line drawn from central Ohio eastwardly through southern Pennsylvania to the Cumberland coal basin, one finds gentle dips, rarely exceeding one or two degrees, until the Coke basin is reached at, say, 50 miles southeast from Pittsburg, where they become steeper, reaching 4° or 5° in the bottom of the trough, and becoming 10° to 12° on the side of the Chestnut hill anticlinal. Eastward no material change in rate of dip is found until beyond the Alleghany mountain, the westward dip in that monoclinal seldom exceeding 10°. To all intents and purposes, the dips in the first and second bituminous basins, as well as in the first subdivision of the third, are the same; the last, however, the most westerly, shows a higher dip in the bottom of the trough than is seen in the others. But in the strip between the Alleghany and the North or Kittatinny mountain the folds are numerous, often bold anticlinals cut into monoclinals, showing Lower Silurian or even Cambrian rocks in the intervening valleys, while still further toward the Blue ridge, in the Great valley, inverted folds are by no means rare.

## Extent of Deformation of the several Coal Basins.

If, however, one study the conditions on either side of this line he will find that it is by no means representative of the conditions for any extended area north or south from it. Northward, in all of the basins the folding diminishes and the axes are insignificant long before the plateau area of northern Pennsylvania and southern New York has been reached; the structure becomes simpler as the evidences of disturbance become less in that direction. Thus, between the Alleghany and the Kittatinny, the many and great folds of Maryland and of the southern counties of Pennsylvania become fewer and less bold, the synclinals broader and deeper; so that instead of the single area of Coal Measures, that of Broad Top (itself due to the northward decrease of three strong anticlinals), one finds the several anthracite fields in northeastern Pennsylvania. The same general statement holds good with respect to the other basins. Southward the condition is similar except in the strip east from the Alleghany mountain, and yet the difference is very noteworthy. The degree of disturbance in the region west from the Alleghany steadily decreases southward along the strike, and the basins soon become merged; at least, the folds limiting them become so gentle as to be followed with some difficulty. Even the magnificent anticlinal representing the Alleghany alongside of the Cumberland coal-field in Maryland, after attaining its maximum in Randolph county of West Virginia, quickly diminishes so as to cause comparatively small interruptions in the dip on the lower New river—just enough to keep the Coal Measures from passing under that stream for a long distance. The contrast between the southern and the northern conditions is very great. At the north the basins are canoe-shaped and become shallower, the bottom rising so that lower and lower rocks appear in succession as the higher ones pass into the air. At the south, in West Virginia, the anticlinals are lowered so that the higher rocks pass over them. Thus the detached prongs of the Upper Coal Measures in southern Pennsylvania become united as the Pittsburg coal bed crosses the diminishing anticlinals. The Chestnut hill anticlinal attains its maximum in southern Pennsylvania, near the old National road, where the upper Chemung, to a thickness of several hundred feet, is exposed at the summit, about 2,500 feet above tide. But at barely 40 miles away, in West Virginia, the Pottsville crosses this fold at 989 feet above tide, while at 20 miles further the Pittsburg coal-bed also crosses the axis at a slightly greater altitude. The depression of the fold in this interval is not less than 2,300 feet. It is probably much more, because the Carboniferous groups thicken rapidly in that direction. There is then a decrease of disturbance southward toward the border of Kentucky and Tennessee in these so-called bituminous basins.

The conditions in the strip between the Alleghany and Kittatinny mountains are quite different. Extensive coal areas exist further northward, measured along the strike, than in the other region, for the great eastward curve of the Blue ridge in the northerly portion makes possible broader and less abrupt folds; but from central Pennsylvania southward the strip becomes narrower and the folding more abrupt. Faults become more markedly characteristic until in central and southern Virginia they are to be looked for as the natural explanation of irregularities on the eastern side of the strip. So much is this the case that one cannot well draw a line by which to separate in southern Virginia the two areas of Pennsylvania between the Alleghany mountain and the Blue ridge. The Pocono coals are exposed again and again by the faults even in the Great valley, while the Coal Measures, in what must be taken as equivalent to the anthracite strip of Pennsylvania, are involved for long distances in the faulted areas. The extent of the disturbance in Virginia is much greater than at any locality in Pennsylvania, the faulting sometimes exceeding 12,000 feet.

It is sufficiently clear that to generalize from the conditions of structure observed along the line from central Ohio across southern Pennsylvania, without careful consideration of the conditions both north and south from that line would be dangerous, as liable to lead to serious error.

## ANTHRACITE OF ARKANSAS.

Variation in proportion of volatile combustible matter, such as is observed in Pennsylvania, occurs in other regions. The one of most interest in this connection is that of western Arkansas.

The existence of anthracite or semi-anthracite in western Arkansas was announced by Dr. D. D. Owen* thirty-five years ago in his description of the coal mine at Spadra, in Johnson county. Additional notes respecting the coals of Johnson county were given in a later report;† but Dr. Owen's study of the coals was merely such as could be made during a preliminary reconnoissance, so that the relations of these beds to those in counties further west or in the area immediately beyond, within Indian territory, were not determined.

The first distinct statement respecting the succession of the Coal Measures in western Arkansas was given by Mr Winslow.‡ He found about 3,750 feet of measures, which he separates into three divisions:

| | |
|---|---|
| The Western or Upper Coal-bearing Division, consisting of sandstone and shale | 3,000 feet. |
| The Intermediate Barren Division, consisting of shale and sandstone | 500 feet. |
| The Eastern or Lower Coal-bearing Division, consisting of dark fissile shale | 250 feet. |

* Owen: First Report of a Geological Reconnaissance of the northern Counties of Arkansas, 1858, p. 130 et seq.

† Owen: Second Report of a Geological Reconnaissance of the middle and southern Counties of Arkansas, 1860, pp. 84–85.

‡ Annual Report of the Geological Survey of Arkansas for 1888, vol. iii. The Geology of the Coal Regions, by Arthur Winslow, pp. 10–26.

The coal-beds of the upper division are thin and variable, but one, near the bottom, is mined at many localities between the state line at the west and Johnson county at the east. The Intermediate division is practically barren, though occasionally a bed develops into local importance. One opening in northeast Franklin county yields a coal whose composition is not without interest in a discussion of some hypotheses. The Lower division contains a persistent bed near the bottom which is mined in Johnson and Pope counties.

Dr. Owen gives results of analyses of coals collected by him, but they differ so radically from those obtained by Professor Brackett for the recent Geological Survey of Arkansas and given in Mr Winslow's report that the two series cannot be compared.*

The results of analyses presented by Mr Winslow are instructive in view of some theories which have been offered to account for the variation in volatile in the coals of Pennsylvania and elsewhere, and reference to them will be made more than once in the pages to follow. The distance from the state line to the last mine at the east, represented in the analyses, is not more than 64 miles, and there is an intermediate space of nearly 26 miles between the first group of analyses near the state line and the second group in the more easterly counties; yet the illustration suffices for the purposes of this discussion. Arranged in geographical order, the results show—

First. That the coal of the upper division contains more of volatile combustible matter than does that of the lower division, even where the localities are but little separated.

Second. That, in a general way, the decrease in proportion of volatile combustible is in an easterly direction.

The latter statement must be made in this qualified manner. The lowest percentage of volatile is in the eastern counties, but the decrease in that direction is by no means regular. The analyses are numbered from the highest volatile to the lowest, number 27 being the semi-anthracite. I have arranged those which are nearly on the same line according to their geographic position, giving under each its approximate distance in miles east from the state line.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Upper division: | | | | | | | | | | |
| Numbers | 4 | 12 | 19 | 1 | 16 | 8 | 14 | 15 | 3 | 18 |
| Miles | 2 | 5 | 10 | 11 | 13 | 24 | 26 | 38 | 40 | 41 |
| Intermediate division: | | | | | | | | | | |
| Number | | | | | | | | | | 5 |
| Miles | | | | | | | | | | 39 |

* The difference must be due to the method of sampling. The remarkable purity of the Spadra coal, as shown by the Owen analyses, suggests that only hand specimens were used, whereas the results obtained by Professor Brackett indicate careful sampling.

Lower division:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Numbers | 24 | 23 | 26 | 22 | 25 | 21 | 27 |
| Miles | 40 | 42 | 50 | 51 | 56 | 70 | 72 |

Despite these anomalies, which tell us that much remains to be learned respecting the variations in these coals, there can be no doubt that the proportion of volatile is less at the east than at the west, and the contrast becomes more marked if the comparison be made with the western extension of this field in Indian territory, for there the percentage of volatile rises to 30, giving a fuel ratio of 2.11, whereas the lowest ratio given by Mr Winslow for Arkansas is 3.51.

Mr Winslow calls attention to the fact that the decrease in volatile is in the direction of decreasing disturbance in the rocks; that in the western counties there is a system of flexures recalling the Pennsylvania conditions, but no such system exists in the anthracitic counties where "there are very few folds of any kind and a nearly horizontal stratigraphy characterizes the coal areas."

## Anthracite Field of Donetz, Russia.

A brief reference may be made to the anthracite field in southern Russia west from the Donetz river which Murchison* has described. If one follow any of the zones along the strike from the tracts where limestone abounds, he finds the calcareous matter thinning out toward the east, and with this alteration comes a great decrease in the "carbonaceous matter," the bituminous coal disappearing and its place being taken by anthracite. In proceeding from north by west to south by east through the hilly steppes north from Novo Tscherkash one finds the limestone thinning out to insignificant bands, while the sandstones and shales become hard. With these changes in the associated rocks the coal seams become less and less bituminous until they assume all the characters of pure anthracite.

Murchison notes that the line of the anthracite coal coincides with that of the crystalline axis of the southern steppes.

## Variation in the volatile Combustibles in Pennsylvania Coals.

The apparent law of variation in volatile combustible material so attracted the attention of Pennsylvania geologists that efforts have been made more than once to formulate a satisfactory hypothesis, accounting not for the origin of anthracite as such, but for the origin of the Pennsylvania anthracite, associated, as it is, with all intermediate grades and

*Murchison: Geology of Russia and the Ural Mountains, vol. i, pp. 100, 101.

forming a regular series to bituminous coal with very high percentage of volatile.*

*HYPOTHESES AS TO CAUSES OF VARIATION.*

*Rogers's Hypothesis.*—The first elaborate discussion was that presented by Professor H. D. Rogers† at the third meeting of the American Association of Geologists. He states that "there prevails a very interesting law of gradation in the quantity of the volatile matter belonging to the coal, as we cross the Appalachian basin from the southeast to the northwest." This law involves "a progressive increase in the proportion of the volatile matter, passing from a nearly total deficiency of it in the driest anthracites to an ample abundance in the richest coking coal." This conclusion is based upon "a multiplied chemical analysis" and is regarded as applicable to the whole region between the northeastern termination of the Coal Measures in Pennsylvania to the latitude of Tennessee.

He describes the several basins and discusses the character of the coal in each.

First. "The southeastern chain of basins," answering practically to the region between the Alleghany and the Kittatinny, but embracing at least part of the Great valley in Virginia. Here he finds the coal to be anthracite for the most part, with some slightly bituminous fields as Broad Top and the areas in Virginia, the volatile varying from 6 to 12 or 14 per cent.

Second. The well defined range of basins immediately northwest of the Alleghany mountain in Pennsylvania, the Potomac basin in nearly the same line and the coal-fields of Big and Little Sewell mountains on the Kanawha and lower New river of West Virginia. The undulations are broad and gentle, the region being west of steep flexures and beyond all considerable dislocations. The volatile varies from 16 to 22 per cent. This includes the first and second bituminous basins of Pennsylvania.

Third. The great Appalachian basin, which includes the third and remaining bituminous basins in Pennsylvania, as well as their southern

*Professor Persifor Frazer has shown (Trans. Amer. Inst. Mining Engineers, vol. vi, ) that it is impossible to compare coals unless the impurities be ignored. He recommended a return to the method used by Professer Johnson many years ago, in which the ratio between the volatile and the fixed combustible matter was used as the basis of comparison. The formula is $\frac{C}{V\ H-C}$ the fixed carbon divided by the volatile hydrocarbon. Thus the grouping becomes—

| | |
|---|---|
| Hard dry anthracite | 100 to 12 |
| Semi-anthracite | 12 to 8 |
| Semi-bituminous | 8 to 5 |
| Bituminous | 5 to 0 |

†Rogers: Reports of the First, Second and Third Meetings of the Association of American Geologists and Naturalists, 1843, p. 470 et seq.

extension in West Virginia, Ohio and Kentucky. The folds are gent'e and the bituminization increases northwestward from 31 per cent. at th southeast to 40 or 43 per cent. near the western side of Pennsylvania and on the Kanawha river in West Virginia.

The variation in degree of bituminization of the coal in different portions of the region is attributed to the prodigious quantity of intensely heated steam and gaseous matter escaping through crevices necessarily produced during the permanent bending of the strata. The elevation of the coal rocks must have been accompanied by the escape of an immense amount of hot vapors, whose influence cannot be overlooked upon any hypothesis of the rending and elevation of great mountain tracts. The coal throughout the eastern basins, if thus effectually steamed, would discharge more or less of its volatile constituents as the strata were more or less violently undulated by earthquake action. The more western beds, more remote from the scene of violent action, less crushed and broken, would be less extensively debituminized.

The entire absence of true eruptive rocks in the anthracite fields, which might have caused the change, is a circumstance which lends great support to this theory. The bitumen in the coal augments westward, precisely as the flexures diminish. No such law of gradation could result from transmission of heat from the general lava mass below the crust, for that would involve a corresponding increasing gradation in thickness of crust westward, which is in conflict with the diminishing thickness of Appalachian rocks westward and contrary to correct geothermal considerations.

Professor Rogers resumed the discussion in his final report,* and gave additional matter respecting the variation of volatile in the anthracite basins. The increase of volatile is not along a northwest and southeast line, but along an east and west line, "or, perhaps, more exactly, toward the west-northwest." The occurrence of semi-anthracite as well as of semi-bituminous coal in the Southern anthracite field is described. The absence of semi-bituminous in the other anthracite fields is accounted for by the fact that they do not extend far enough to the westward, reaching, as they do, barely to the line of semi-anthracite in the Southern field. There is a decided increase in volatile westward in these fields.† The intensely anthracitic condition at the easterly end of the basins is accounted for by proximity to the region of dikes, which are especially numerous between the Delaware and Schuylkill rivers, but less abundant between the latter stream and the Susquehanna. Professor Rogers calls attention to the cracked or jointed condition of the coal as affording means for rapid escape of the gases.

* Rogers: The Geology of Pennsylvania, vol. 2, 1858, p. 995 et seq.
† This, it must be remembered, is in the direction of trend.

*Owen's Hypothesis.*—The occurrence of anthracite coal in Arkansas among undisturbed rocks and at 60 miles away from the nearest igneous rocks led Dr D. D. Owen* to surmise that the heat necessary for the conversion of bituminous coal into anthracite must have been derived from "granite and other hypogene (nether-born) rocks" near enough the surface to have permeated the strata with heated vapors or gases, which expelled the greater part of the gaseous matter, or else the coal has been subject to some extraordinary chemical agency by which $CH_4$ has been removed. He cannot think that the Spadra coal, so different from that only a few miles further west, can owe its present composition to any difference in the vegetation. Its "peculiar fissured structure favors the idea that the volatile matter has been expelled by a process more rapid than can be attributed to slow chemical changes, unaided by an elevation of temperature."

*Stevenson's Hypothesis.*—In 1877 J. J. Stevenson,† discussing the variations of volatile shown by the Pittsburg coal-bed in southwestern Pennsylvania and the adjacent portion of West Virginia and Maryland, antagonized the theory that debituminization of the coal toward the southeast is due to increased disturbance in that direction. He showed that there is practically no increase in extent of disturbance from the first subdivision of the third bituminous basin southeastward to the first bituminous basin, so that heat due to the transformation of mechanical force cannot be regarded as the cause to which the debituminization is due. He gave illustrations of noteworthy changes in structure of the coal-bed eastward in the several basins, and concluded that the difference in volatile is due to difference in conditions under which the coal was formed.

*Lesley's Hypothesis.*—In 1879 Professor J. P. Lesley‡ inserted a discussion of this question into Mr A. S. McCreath's second report on the chemical work of the survey. In this he tabulated the analyses presented by Mr McCreath in the previous pages and, after comparing them, offered some suggestions, each of which deserves serious consideration.

He suggests, first, that the percentage of fixed carbon ought to increase with depth of the coal beneath the surface, for the earth's temperature increases one degree Fahrenheit for every 50 or 60 feet of depth. In western Pennsylvania, however, under present conditions, the effect of this increment in temperature must be insignificant, as the lowest coal-bed, the Sharon, is but 1,600 feet below the Washington, the highest of

*Owen: First Report of a Geological Reconnaissance of the northern Counties of Arkansas, 1858, p. 131.

†Stevenson: Second Geol. Survey of Penn., Report of Progress in the Fayette and Westmoreland District, etc., part i, 1877, p. 61 et seq.

‡Lesley: Second Geol. Survey of Penn., Second Report of Progress in the Laboratory, etc., 1879, p. 153 et seq.

the considerable beds, while the latter is but 1,100 feet below the highest stratum recognized in that portion of the Appalachian basin. Considering the whole of this 2,700 feet of rock upon the Sharon, that bed should have a constant temperature of not far from 100° F. in Washington county of Pennsylvania or about 30 degrees more than that of the Washington coal-bed when it underlay the 1,100 feet. Comparing the fuel ratios he finds in the two coals—Washington, 1.19; Sharon (block), 1.52—a difference of 0.33 in favor of the lower bed, which may be due to greater depth of cover or to difference in botany or to our having too few analyses for obtaining trustworthy ratios or to other unknown or unsuggested causes.

He calls attention to the fact that our knowledge is incomplete respecting the extent of the Coal Measures section; that we know nothing respecting higher measures once existing in southwestern Pennsylvania, but now eroded and swept away. In the deeper anthracite basins the Coal Measures, above the Pottsville conglomerate, are 3,000 or more feet thick; and the type of the topography shows that still higher rocks must have existed, though now they have been removed. He discusses the distribution of the Permian beds, and considers that they must have increased eastward, as do the other members of the series, so as to make the top covering very thick in the anthracite fields and thinner in the bituminous fields. In such case the coal-beds will appear to have been subjected to more earth-heat in the east and to less earth-heat in the west, and their carbon ratios (so far as this cause is supposed to operate) will be presumably higher in the east than in the west, as it undoubtedly is.

A second suggestion arises out of the hypothesis that anthracite is due to greater oxidation of the vegetable matter. Why should the beds of the anthracite basins be more oxidized than those of the bituminous fields? The rocks in the undisturbed western fields consist largely of clay, while those of the eastern fields consist more largely of sand and gravel strata, so that oxidation would be more favored in the latter. More, the undisturbed clays of the west lute down and almost hermetically seal the underground coals; the disturbed, semi-metamorphosed and cracked-up clay-slates of the east expose their coals throughout to percolation, evaporation and oxidation. The regions differ in—

1. Heavier covering of Permian at the east, raising earth-heat of the anthracite beds.

2. Greater constitutional looseness of whole pile of deposits in the east, facilitating percolation and oxidation.

3. Universal fracturing of the whole pile at the east, facilitating the exit of the volatile hydrocarbon.

Professor Lesley suggests, in addition, the factor of pressure and that of plant variation. All of these suggestions were offered merely as suggestions, not to formulate any hypothesis, but that others may be led to a careful consideration of the matter.

## Discussion of Hypotheses based on Necessity of Metamorphism.

Rogers and Owen regard anthracite as due to metamorphism and Lesley appears to favor the same theory of origin. Each of these geologists presents a hypothesis respecting the origin of the heat causing the metamorphism.

### *ANTHRACITE CAN BE FORMED BY CONTACT WITH HEATED ROCK.*

Unquestionably, heat is sufficient, under proper conditions, for the conversion of bituminous coal into anthracite. The localities in which that conversion has occurred are too numerous to admit of question in this connection.

*Examples of Contact-alteration in New Mexico.*—Newberry, Le Conte, Hayden and Stevenson have referred in various publications to the small Placer coal-field about 25 miles south from Santa Fé, New Mexico. There the conditions are perfectly clear. The coal is bituminous near Galisteo creek, but is found becoming less and less so as one ascends the arroyos (dry water-courses) leading up the mountain side, until at length it is an anthracite, with 13 as its ratio. The change was produced by an enormous trachyte dike, which cuts all the beds along the northerly face of the mountain, but the extent of change becomes distinctly less as distance from the dike increases. This little field gives a positive illustration that something more than the mere contact with molten rock is needed to cause metamorphism, for in an arroyo leading up from Galisteo creek a narrow dike of basalt has cut two thin beds of coal, which appear to be unchanged even at the contact, for pieces taken thence burned with abundant flame.* Many canyons in the Trinidad coal-field of northern New Mexico show coal converted into coke† by intruded sheets of basalt. No anthracite has been observed in this field, but the coke is usually denser than that obtained in Belgian ovens. Fragments of graphite have been reported from one exposure on the Upper Canadian river.

*Example of Contact-alteration in Colorado.*—The Elk mountains of central Colorado hold an area of anthracite which was described by W. H. Holmes ‡ and Dr A. C. Peale § in 1876, the exposures having been ex-

*Stevenson: U. S. Geograph. Surveys west of the 100th Meridian, vol. iii, 1881, suppl., p. 332.

† Loc. cit., pp. 204, 208, 216, 268.

‡ Holmes: Ann. Rep. of the U. S. Geol. and Geog. Survey of the Territories for 1874, p. 67.

§ Peale in same, pp. 98, 99, 139, 176.

amined by them in 1874. Those observers regard the change as due to the influence of eruptive rocks.

*Examples of Contact-alteration in Virginia and North Carolina.*—The well-known conditions in the coal-fields of eastern Virginia and of North Carolina render those areas equally illustrative. Dikes passing across the coal in Virginia have changed it in many places into coke, which at one time was sold in eastern markets under the name of James river carbonite. Anthracite has been formed under similar circumstances at some localities in North Carolina.

*Examples of Contact-alteration in New Zealand.*—Dr Haast * made many references to the occurrence in New Zealand of coal altered by contact with dolerite; sometimes coked, at other times changed wholly into anthracite. In the same report Dr Haast tells of the Hesse Cassel brown coals, altered by basalt sheets, which in many cases form both roof and floor of the seams. Occasionally, where the flow was small, the effect is insignificant. The mode of change is well exhibited near the Meissner, where the mines have been worked for two hundred years. The seams, for the most part, are from 20 to 30 feet thick, and are changed only in part. The effect of the heat extends from 7 to 17 feet, according to the thickness of the overlying basalt. Immediately below that rock, for from 1 to 4 feet, the change into anthracite is usually complete, but thence downward the passage is gradual to the wholly unchanged brown coal. Dr Haast describes a condition very like that observed in our own Placer field, a coal-bed in contact with a dolerite dike is changed into anthracite, but the change becomes less as distance from the dike increases, until the normal "pitch coal" is reached. Dr Hector in the same report adds some interesting notes † to Dr Haast's observations.

*Alteration through Contact not invariable.*—While it seems to be sufficiently clear that bituminous coal can be converted into anthracite by the agency of heat, it must be remembered that there are localities where intrusions of lava have been without influence, and that there are others where, as will be shown, notable folding and crushing have been ineffective, and that there are others where close proximity to granite and other crystalline rocks has led to no change.

## *OBJECTIONS TO ROGERS'S HYPOTHESIS.*

Two fundamental assumptions in the hypothesis offered by Professor Rogers are erroneous: First, that anthracite is necessarily due to metamorphism, and, second, that the plication of the Appalachian region was

* Haast: Geol. Survey of New Zealand; Reports of geological Explorations during 1871-'72, pp. 51, 52, 54, 82.

† Hector: Loc. cit., p. 147.

cataclysmic and deep-seated. Nothing need be said at this stage respecting the former, but reference to the latter is necessary.

*Appalachians not cataclysmic in Origin.*—Possibly the writer may have been wrong in imagining that the plication advanced so slowly as not to interfere with the main water-courses,* but the drainage in Pennsylvania, Maryland, Virginia and West Virginia certainly suggests that the more important streams antedated the folds, for they cross and recross the great anticlinals, synclinals and faults by gaps, in whose walls the rocks are true to dip and strike. Another explanation is possible without calling in the aid of cataclysms. The plication was not so slow everywhere as to permit readjustment of the rock particles without crushing. The great Pocono sandstone in Fulton county of Pennsylvania, more than 1,000 feet thick, was broken into enormous wedges, which were moved one on the other until the contact surfaces were polished, the irregular crevices remaining being filled afterward by thin films of quartz, sufficiently distinct wherever the sandstones are exposed.† The Utica shale in the Great valley of Pennsylvania, as shown in the approaches to the tunnels of the South Pennsylvania railroad, is crushed into lenticular fragments, now polished and closely packed together. In some of the Broad Top mines the coal has suffered similar treatment, with the same result. Such crushing occurs rarely in the less sharply folded area west from the Alleghany, but even there is not altogether wanting, for the coal is often prismatic and jointing is frequently so extensive as to injure sandstone for building purposes.

But G. K. Gilbert‡ asserts that this crushing cannot extend deeply; that there is little possibility of its reaching downward even to ten miles; certainly, then, the fissuring would not be deep enough to afford escape for heated vapors and gases from the interior of the earth.

The plication, resulting in the Appalachian revolution, began at an early date, as is evident from existence of canoe-shaped synclinals, dating back to the middle Coal Measures, and of subaërial erosion, sometimes of great extent in Ohio and Pennsylvania Coal Measures. Indeed, the folding began far back in geologic time, and the Appalachian basin, closed, it may be, only by a long bar at the west during the Devonian, was crumpled in the latter part of that age just as it was during the early and middle Carboniferous, though less extensively.§

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* Stevenson: Proc. Amer. Philos. Society, vol. xviii, 1879, p. 306.

† Stevenson: Proc. Amer. Philos. Society, vol. xxi, 1884, p. 165.

‡ Gilbert: Bulletin of the Geol. Soc. of Amer., vol. i, 1890, p. 27.

§ For facts referred to in this paragraph see Newberry: Geol. Survey of Ohio, vol. 2, part 1, 1874, p. 117; M. C. Reid: Geol. Survey of Ohio, vol. 3, part 1, 1878, p. 572; Stevenson: Annals Lyc. Nat Hist. N. Y., vol. x, 1873, p. 235; also in Second Geol. Survey of Penn., Fayette and Westmoreland District, part 2, 1878, pp. 271–282.

*Erroneous Conclusions as to Relation of Disturbance to Amount of Volatile.*— The first serious error in Professor Rogers's discussion is in reference to the relation of increase in dip to decrease in volatile combustible matter. He believed that the increase in rate of dip is steady and marked along a west-northwest and east-southeast line. True, the dip does increase from Pittsburg along that line to the Cumberland (Potomac) basin in Maryland; and the increase is remarkable if one compare the extremities of the line; but the increase is not regular. As was stated on a previous page, the increase is moderately great from Pittsburg to the foot of Chestnut ridge in the Connellsville basin, from 1° at Pittsburg to 10° on the side of Chestnut ridge; but there is no further increase until beyond the Alleghany mountain, for in that monoclinal one rarely finds a dip of more than 10° near the line under consideration; but immediately beyond the Alleghany one comes to great folds, with dips of from 20° to 50°, sometimes with inversions. The dip on the easterly side of the Cumberland basin (the Mount Savage synclinal) within Bedford county of Pennsylvania is sometimes more than 80°.*

Along the line chosen by Professor Rogers the Pittsburg coal-bed shows the following variations, the results being the average of analyses in each basin and the calculations being made without reference to water and ash: Pittsburg, 40.7; in the next trough eastward, 39.2; in the Greensburg, 35.3; in the Connellsville or Coke, 33.8; there the dip is from 4° to 6° in the mines; in the Ligonier valley, 28.1; in the Salisbury basin of Somerset county, 23.3; in the Cumberland basin of Maryland, 18.8. The decrease in proportion of volatile matter is greater in passing from Connellsville to Salisbury, about 34 miles along the dip, with *no* change in type or extent of disturbance, than it is in passing from Pittsburg to Connellsville, about 32 miles, with *great* change, or from Salisbury to Frostburg, in the Cumberland basin, about 15 miles, with the *extreme* change in extent and type of disturbance on both sides of the Cumberland basin.

It is very true that, along a similarly east-southeast and west-northwest line across the anthracite fields, a great increase of complexity is observed toward the east. The area of greatest disturbance is in the Great valley beyond the Southern anthracite field; folding is much more marked and the distortion is much greater in that field than in the others; the flexures become broader and gentler toward the northwest, so that in the Northern anthracite field one finds a typical canoe basin, with only moderate dips, while the Loyalsock or Bernice, still further northwest

*Second Geol. Survey Penn. Rep. on Bedford and Fulton Counties, 1882, p. 104. For notes respecting the conditions in West Virginia, see I. C. White: Proc. Amer. Philos. Society, vol. xix, 1881, p. 438 et seq.

(the northern termination of the first bituminous basin), though containing anthracite coals, has dips varying from 3 to 5 feet per hundred.* But, as will be shown later on, this increase in complexity bears no relation whatever to the character of the coal in the several anthracite fields.

*Neglect of Conditions observable in the individual Basins.*—A notable source of error in the discussion lay in neglect of the conditions observable along the trend in the several basins. From Pittsburg east-southeast to Frostburg, in the Cumberland basin, one finds the conditions already noted, with greatly increased disturbance beyond that basin. But let it be remembered that the extent of disturbance diminishes northward in all the basins; that the folding in and around the Middle and Northern anthracite fields is less than that in and around the Broad Top of southern Pennsylvania and the Cumberland in Maryland; that the flexures in the Loyalsock are less pronounced than those in Somerset county of Pennsylvania, in the southern portion of the same first bituminous basin.

*Discontinuity of Rogers's Line connecting anthracite and bituminous Basins.*—A still more serious error was that of extending this single line beyond the Cumberland basin across the anthracite fields. The line from Pittsburg to Frostburg or to the Broad Top field is not continuous with that across the anthracite fields; its eastern portion is parallel to the latter line, and is equivalent to the line passing through the Northern and Middle fields. There is no certainty in the impression that if the line were continued beyond the Broad Top field or the Cumberland basin anthracite conditions would be reached.† As has been stated on a former page, the Broad Top coal-field may be taken fairly as representing the Northern field.

*True Statement of Relation of Disturbance to Amount of Volatile.*—The true statement is that the decrease in volatile combustible matter, as shown in the easterly basins, is not merely toward the east, but also and more notably toward the north, along the trend, and apparently without any relation whatever to the degree of the disturbance; for in the former case the decrease is in the general direction of increase of disturbance; in the latter, the decrease is in the general direction of decrease of disturbance. Not to multiply details here, as they will be needed in another part of this discussion, it suffices to emphasize two facts: The driest anthracite is not found in the Southern anthracite field, which contains the most

*Ashburner: Ann. Rep. Second Geol. Survey Penn. for 1885, pp. 283–284.

†This statement is made cautiously, for in northern Virginia the Pocono coals, lying in a line with the Southern anthracite field, sometimes approach anthracite, but the ratios show extreme variations.

folded and distorted basins, but in the Middle fields. The hardest anthracite is not found in the southwesterly or most plicated portion of the Southern field. There semi-anthracite, even semi-bituminous, occurs, while the harder anthracite is obtained at the other end of the field, where the condition is becoming more like that of the other anthracite fields.

*Influence of Dikes insignificant.*—It seems hardly necessary to refer to the supposed influence of dikes in causing the greater hardness of coal at the northerly end of the southern basin. It is well known that such influence can be exerted to but a little distance. The coal-fields near Richmond, Virginia, have been intersected by dikes sufficiently to test this matter; but there are few coals richer in volatile conbustible than those near Richmond. The dikes in northeastern Pennsylvania are extensive, but they could not be a factor in this matter.

*Columnar Structure not Evidence of loss of Volatile through Consolidation.*—Columnar structure gives no evidence in favor of the supposition that the coal has been subjected to the loss of volatile after consolidation. The Imboden coal of Wise county, Virginia, with about 37 per cent; the Pocahontas coal of Virginia, with 21 per cent; the Pittsburg coal on Scotts run, in Monongalia county of West Virginia, with nearly 40 per cent, and the same coal near Uniontown, Pennsylvania, with 36 per cent of volatile, all have this structure almost equally well marked.

## *OBJECTIONS TO HYPOTHESIS OF MURCHISON AND OWEN.*

Murchison notes that the line of the anthracite coal in the field west from the Donetz river, Russia, coincides with that of the crystalline axis of the southern steppes, and suggests that the igneous rocks of that axis in their subterranean prolongation may have converted the superficial coal into anthracite while hardening the grits and sandstones and shale; but there is need of proof that granitic and schistose rocks have any metamorphosing power. The change in those rocks must have been complete that they might be available as hypogene rocks to support the coal. Certainly the coal-fields of eastern Virginia occupying basins in the metamorphic rocks show no change due to the influence of those rocks. It is much more likely that the crystalline axis of the steppes formed the shoreline of the region from which the coal marshes extended into the basins. The change in type of rock and the disappearance of the limestones in that direction go to show the proximity of a shoreline.

Dr. Owen's explanation is of the same sort. No rocks of igneous or of metamorphic origin are to be seen anywhere near the coal-field; but their presence is necessary to the hypothesis that the coal is metamorphic, and they are supposed to be at no considerable distance below the surface.

### OBJECTIONS TO LESLEY'S HYPOTHESIS.

*Increased Rock-covering not productive of increased Heat.*—Professor Lesley suggests that the increased thickness of overlying rock might lead to increased heat in the lower beds. He illustrates his point by comparison of analyses of coal from the Washington and the Sharon beds, the two available extremes of the column in western Pennsylvania; but the comparison is insufficient, since comparison of the Washington coal with coal from the Mercer and Quakertown beds, belonging at approximately the same horizon with the Sharon, gives a contrary result.*

*No increased Rock-covering in Anthracite Region.*—Professor Lesley, accepting this suggestion as a possible explanation of varying percentages of volatile combustible matter, applies it to explain debituminization of the coals of eastern Pennsylvania. He maintains that as the Paleozoic groups thicken toward the east, there is every reason to suppose that the Permo-Carboniferous, existing in southwest Pennsylvania and in West Virginia, must have extended into the anthracite region with constantly increasing thickness, so that one should expect to find, as he does find, the coal with very much less volatile there than in the region west from the Alleghany mountain.

The supposition that the coal groups thicken eastward toward the anthracite region is hardly in accordance with the facts, as recorded in the reports of the Pennsylvania survey.† It is altogether true that the Devonian and lower rocks have their greatest thickness at the east, and that they do decrease with great rapidity westward, even within the limits of Pennsylvania; but this is not altogether true of the Coal Measures groups, especially of the higher groups, which lose thickness as they recede from southwest Pennsylvania, north, east and west. This general statement is necessary, for the old conception still prevails too widely that the same law of decrease holds good for the Coal Measures as for the lower groups; but the conditions had changed at the end of the Devonian, so that the Cincinnati arch at that time, whatever it may have been during the Devonian, had become more than a bar, had become a low upland, with drainage enough to bring down not very coarse material for the sandstones of the Coal Measures. The Coal Measures were deposited in an almost land-locked basin, along whose central strip lime-

* Second Report of Progress in the Laboratory, etc, 1879, pp. 146–147.

† Many of these were published after Professor Lesley's discussion was prepared.

stones were formed. The old grouping of the Coal Measures in Pennsylvania answers best for comparison. It is, in ascending order—

1. Pottsville.
2. Lower coal group.
3. Lower barren group.
4. Upper coal group.
5. Upper barren group or Permo-Carboniferous.

The Pottsville conglomerate within the anthracite fields varies in thickness, according to Ashburner,* from 551 to 1,280 feet in the Southern field, whereas in the Middle field, near Hazleton, it is but 262 feet, while near Wilkesbarre, in the Northern field, it is but 96 feet. The variations in thickness occur within short distances and are very startling. The causes do not concern us here. In the Broad Top region the thickness of the Pottsville is not far from 250 feet,† whereas on the east side of the Cumberland basin, along the Baltimore and Ohio railroad, in West Virginia, it is 451 feet.‡ Its lower plate disappears in southwest Pennsylvania, where the total thickness is not far from 200 feet.§

The lower coal group,|| taking the Mammoth bed as its upper limit, shows an extreme thickness of 500 to 437 feet in the Southern field; of 213 to 156 feet in the Middle field and of 476 to 257 feet in the Northern field. In the semi-bituminous Broad Top field the extreme thickness is barely 220 feet,¶ and on the eastern side of the Cumberland basin, on the Baltimore and Ohio railroad, it is only 268 feet.** These are all within the strip between the Alleghany and the Kittatinny mountain—the anthracite strip; but in the bituminous basins the thickness of this group varies from 300 to 350 feet, as given by White, Platt and Stevenson in their several reports.

The lower barren group in Broad Top is about 520 feet, and about 600 feet on the east side of the Cumberland basin. No positive statement can be made respecting its thickness in the anthracite field, as the identification of the Pittsburg coal-bed there is not wholly certain, but it is approximately the same as in Broad Top. In the bituminous areas, according to White, Platt and Stevenson, the thickness varies from 570 to 610 feet.

* Ashburner: Ann. Rep. Geol. Survey of Pennsylvania for 1885, p. 294.

† Stevenson: Second Geol. Survey of Pennsylvania; Geology of Bedford and Fulton Counties, 1882, p. 65.

‡ I. C. White: Proc. Amer. Phil. Society, vol. 19, 1881, p. 445.

§ The writer long ago became convinced that he should have placed the coal beds underlying the Pottsville conglomerate of southwest Pennsylvania with the Pottsville instead of in the lower Carboniferous. This correction he made in Am. Jour. Sci., vol. xxxiv, 1887, p. 37.

|| These figures are taken from Ashburner in the Ann. Rep. for 1885.

¶ Geology of Bedford and Fulton Counties, p. 60.

** I. C. White: Proc. Amer. Phil. Society, vol. 19, p. 445.

Thus far, it is sufficiently clear that the comparison affords no basis for the assertion that the Measures are thicker, materially thicker, in the anthracite than in the bituminous regions. It is impossible to make similar comparisons in detail for the upper groups, since they have not been differentiated finally from the lower barren group in the anthracite fields. At the same time, there is no reason to doubt that both the upper coal group and the Permo-Carboniferous are present in the anthracite region, for 2,250 feet of rock are reported * as overlying the Mammoth bed at Pottsville. The Pittsburg bed has been identified with much hesitation in one of the anthracite fields, but there is no doubt respecting the identification in the Cumberland field and but little in the Broad Top field. It is certain, however, that groups 4 and 5 attain their greatest Pennsylvania thickness in the extreme southwest corner of the state, and that in all directions from that locality, within the state, they decrease in thickness. This appears abundantly by comparison of measurements made by Professor I. C. White and by the writer in Ohio and various portions of Pennsylvania.† There is every reason, therefore, to believe that they are less thick in eastern than in western Pennsylvania.

*Increased Rock-covering not found to produce Anthracite.*—Measurements made in Virginia and West Virginia by I. C. White, Fontaine and Stevenson show conclusively that the thickening of the Coal Measures was not greatest, was not even great, in the anthracite region or at any other locality in Pennsylvania. Long ago Fontaine measured the Pottsville group on the New river and announced the thickness to be not far from 1,200 feet. The writer found 1,000 feet in Wise county of Virginia; ‡ while Professor I. C. White measured 1,400 feet at one locality in Fayette county of West Virginia,§ and announced that in Kentucky the thickness reaches 2,000 feet. On the Big Kanawha river of West Virginia Professor White finds the lower coal group 1,006 feet thick, while the lower barren group is 800 feet.‖ Still further south, in Wise county, Virginia, many miles beyond the extreme southern limit of the Pittsburg coal-bed, as determined by Professor White, the writer found 2,348 feet of coal measures above the top of the Pottsville,¶ which can represent only the lower coal group and the lower barren group. It is, therefore, unquestionably certain that the thickness in the anthracite fields is very much less than in eastern Kentucky and the southern portion of the

*Ashburner: Second Geol. Survey Pennsylvania; First Rep. on the Anthracite Coal Region, 1883, p. 239.

† Stevenson: The Fayette and Westmoreland District; 1878, part 2, chap. xxi, pp. 283–295.

‡ Stevenson: Proc. Amer. Philos. Society, vol. 19, 1881, p. 230.

§ I. C. White: Stratigraphy of the Bituminous Coal-field of Pennsylvania, Ohio and West Virginia, Bulletin U. S. Geol. Survey, no. 65, 1891, p. 197.

‖ I. C. White: Loc. cit., pp. 85 and 140.

¶ Proc. Amer. Philos. Society, vol. 19, p. 238.

Virginias; yet there is no anthracite in southwest Virginia or along the Kanawha river. On the contrary, the Imboden coal-bed, toward the bottom of the lower coal group in Wise county, Virginia, has almost as much volatile combustible as the Pittsburg coal-bed has at Pittsburg.

There are instances within the anthracite strip which tempt one to say that the decrease in volatile is in direction of decrease of cover. The Lykens valley coals of the Southern anthracite field, which have as much volatile as the Bernice coals at the extreme northern portion of the first bituminous basin, belong not to the upper coal groups, but to the Pottsville.

An equally satisfactory illustration is found in the Arkansas field. The upper coal division is about 3,000 feet thick and its important coal-bed is near the bottom. The main coal of the lower coal division is at about 750 feet lower in the column. The upper bed has a fuel ratio of 6.15, while that from an opening in the lower bed, less than a mile away, has a fuel ratio of 7.30. That this difference cannot be explained as due to the influence of additional pressure or of increased earth-heat because of the column of 750 feet of rock is evident from the fact that the coal-bed of the intermediate division is opened almost midway between the two localities, and its coal has a fuel ratio of 4.97, much more volatile than is contained in the upper bed.

### *OBJECTIONS TO HYPOTHESIS OF MECHANICAL FORCE TRANSFORMED INTO HEAT.*

*Mallet's Investigations.*—Mallet's investigations, showing the quantity of heat evolved by the crushing of rock, have been a fruitful source of hypotheses respecting metamorphism. There is no room for doubt that such crushing can produce heat; that it might produce heat enough to convert bituminous coal into anthracite; the difficulty is not in the conception of possibility, but in finding evidence of probability. The presumption in every case is against the supposition that the anthracite, granting that it is the result of metamorphism, was metamorphosed by heat due to this agency. The instances of metamorphism unequivocally due to crushing and folding are none too numerous, whereas instances in which no metamorphism has taken place despite the most violent crushing are sufficiently numerous.

*Evidence of the Virginia Coals.*—The Pocono coals in southwest Virginia have been crushed during the folding and faulting of that region until in some localities they are as flaky as pastry crust. The filmy layers can be separated by the fingers, and their surfaces are polished by the chafing which they have endured; yet that coal is rarely more than semi-anthracite, and in some localities it is a semi-bituminous coal. The Pottsville coal at Quinnimont, West Virginia, is in the gently undulated

Sewell mountain region; yet its volatile is no greater than that of the same coal at Pocahontas, in Virginia, at a little way from the Abb's valley fault, whose throw is more than 10,000 feet. The crushed "looking-glass" coal in the Broad Top field is semi-bituminous, while the uncrushed coal of the gently flexed Wyoming field is anthracite. The Barnet bed in the Broad Top field is faulted, but shows coal of the same quality on both sides of the fault. The Imboden coal-bed of Wise county, Virginia, at only a stone's throw from the great overturned anticlinal of Stone mountain, has about 37 per cent of volatile, quite as much as it has miles away at the west in the undisturbed portion of Kentucky.

*Evidence of the Arkansas Coals.*—Mr Winslow's observations in Arkansas afford another illustration which is in place here. Evidently inclined favorably to the doctrine of metamorphism by heat derived from crushing, he regards as somewhat curious the fact that the volatile combustible in the Arkansas coals diminishes as the distance from disturbance increases, for the region of high volatile is traversed by flexures recalling to mind the systems in Pennsylvania, whereas the region of the semi-anthracite is undisturbed.*

## Metamorphism not a sufficient Explanation of the Phenomena.

While there can be no doubt that bituminous coal, heated by contact with molten rock, or by transformation of mechanical force exerted in crushing rock, or by action of gases or vapors from deep-seated sources, may become anthracite, still it must be conceded that in Pennsylvania there is no evidence showing any relation of cause and effect between such agencies and the loss of volatile combustible in the coal. Some explanation other than that depending on metamorphism must be found; for if metamorphism be unnecessary to explain the variation of volatile from 45 to 35 per cent in the same coal-bed within a few rods, it should be equally unnecessary to explain a still further loss of volatile. The more so, in view of the well-known fact that different benches of the same bed at the same opening, where they are separated by only a few inches of clay, show a contrast greater than that between the Pittsburg coal in the Salisbury bituminous basin and the Stoney creek coals of the Southern anthracite field.† The volatile often differs several per cent in the different benches of a coal-bed. Even in the same hillside in the Bernice or Loyalsock field (the northern end of the first bituminous basin) and barely 60 feet apart are two beds, the lower showing a ratio of 4.13,‡ while that of the upper bed is 10.28.

* Winslow: Loc. cit., p. 51.

† Ann. Rep. Second Geol. Survey of Pennsylvania for 1885, pp. 480, 482, 485.

‡ A. S. McCreath: Second Rep. of Progress in the Laboratory, etc, pp. 82–94.

## BISCHOF'S THEORY OF THE FORMATION OF ANTHRACITE.

Long ago Bischof recognized that graphite is of vegetable origin, the mode of its occurrence in coal-beds of Greenland as well as in those near Cumnoch, in Scotland, being such as to leave no room for doubt. As anthracite is intermediate between bituminous coal and graphite, its vegetable origin was conceded of necessity. Lesley* has shown by tabulating the analyses made by A. S. McCreath that the series from the driest anthracite to the richest bituminous coal is almost perfect.

Vegetable matter left exposed upon the ground decays; it is oxidized and loses its own oxygen very rapidly. This process does not convert wood into coal, the escaping gases being carbon-dioxide and water; but under water the change advances differently, so that the carbon and hydrogen unite, and marsh gas as well as the other gases mentioned is set free. Goeppert † found that the decomposition of mosses goes on more slowly as the depth of the water increases; those at 6 to 8 inches below the surface decompose rapidly, but others at 12 to 36 inches were fairly preserved for fifteen months. The character of the decomposition may well assume different characters with varying depths of water. Bischof ‡ thinks that the smaller quantity of volatile hydrocarbons in anthracite fields may be due to the more ready access of water, which favored evolution of marsh gas as well as the other gases. Sterry Hunt § has exhibited the several steps in the process of change from cellulose to bituminous coal by a series of empirical formulas, which show the successive conditions mentioned by Bischof. Green || has illustrated the relations of the several products from wood to anthracite by a table of percentage compositions.

## LESLEY'S SUGGESTION OF OXIDATION.

Professor Lesley uses the process of oxidation as the basis of a suggestion respecting the possible origin of the Pennsylvania anthracite. He lays great stress upon the fact that in the anthracite region there are more of sandy and gravelly rocks than in the bituminous regions, where clayey materials abound, so that oxidation of the coal would be favored in the former more than in the latter. He maintains, further, that the undisturbed clays of the latter lute down and almost hermetically seal the underground coals, whereas the disturbed, semi-metamorphosed and cracked-up clay-slates of the former expose their coals to the very bottom of the series to percolation, evaporation and oxidation.

* Lesley in Second Report of Progress in the Laboratory, etc, 1879, p. 146 et seq.

† Goeppert cited by Bischof, Chemical Geology, vol. i, p. 271.

‡ Bischof: Chemical Geology, vol. i, p. 273, foot-note.

§ Sterry Hunt: Chemical and Geological Essays, 1875, p. 181.

|| Green: Geology, 1882, part i, Physical Geology, p. 182.

*OBJECTIONS TO LESLEY'S SUGGESTION.*

*Undisturbed Areas furnish all Varieties of Coal.*—If we had to deal only with the extremes, with the rich gas-coal of the Pittsburg area and the dry anthracites of the Middle anthracite fields, these suggestions would have greater weight; but we must remember that the practically undisturbed or only gently folded beds of the bituminous basins west from the Alleghany mountain yield every possible gradation, from the richest bituminous coals to the semi-anthracites of the Loyalsock (Bernice) field, the latter having in some cases even less volatile than the Lykens valley coals of the Southern anthracite field. In all of these are found the clay-beds which should prevent percolation and the rest; but it is unnecessary to go outside of the anthracite field for an illustration, for in a single colliery on the Mammoth bed in the Southern anthracite field semi-bituminous, almost bituminous, coal occurs in one bench and hard anthracite in another, the ratios being 5.59 and 51.1.*

The Northern anthracite field, as described by Chance and by Ashburner, is not fractured. It seems to be much less disturbed than is the southern portion of the Broad Top semi-bituminous field. Ashburner's sections show a good deal of clayey material. Taken all in all, the conditions in Broad Top appear to be more favorable to percolation and oxidation than are those in the Northern field, certainly far more favorable than those in the Loyalsock field, if extent of fracturing and thickness of clays be the test.

*Influence of Clay-beds insignificant.*—The presence or absence of the clay-beds evidently has very little to do with the matter. Ashburner's sections in the Northern field show more clay-beds than can be found in a greater thickness of rock within the Black mountain coal-field of southwest Virginia, immediately behind the overturned anticlinal of Stone mountain; yet at half a mile from the vertical beds in that fold the Imboden bed shows a fuel ratio of 1.67, while the Kelly bed, at barely a stone-throw from the vertical beds, has a fuel ratio of 1.48. Certainly this area should be cracked-up enough, for its southeasterly boundary is the Stone mountain anticlinal and the faulted area of southwest Virginia, while its northerly boundary is an enormous fault. An even more satisfactory illustration is found in the southeastern prong of the Southern anthracite field, where, within a dozen miles along the trend, the ratio varies from 4.64 to 12.40.

*Process of Conversion completed prior to Rock-consolidation.*—The suggestion immediately under consideration evidently carries with it the additional suggestion that the change was not complete even when the whole

*A. S. McCreath: Ann. Rep. of Second Geol. Survey of Pennsylvania for 1885, p. 321.

pile of rocks had been deposited, and that the process continued until sometime posterior to the folding and crushing; but it is not easy to understand how percolation would be carried on to any greater extent in the anthracite than in the bituminous region after the folding and consequent erosion had taken place. Those who mine bituminous coal find the water of percolation through the coal itself sufficiently troublesome in western Pennsylvania. Water of this kind would be stagnant in the canoe synclinals, and as its oxygen would soon be converted into carbon dioxide, the process of oxidation would be stopped. Bituminous coal, it is true, when exposed to atmospheric moisture and a slightly increased temperature, does undergo changes in composition somewhat analogous to those which lead to anthracite—changes which appear in most cases to be accompanied with deterioration of the coal, physically. The defects of "crop coal" are well known to all; but conditions such as cause change of coal in the atmosphere cannot be conceived of as existing at a thousand feet below the surface, where the supply of oxygen is very small and where what supply there is is fixed very promptly. In fact, there is ground for believing that the changed condition of "crop coal" is due to mechanical even more than to chemical change.

We can determine one point respecting the time of consolidation. The coal of the Upper Freeport, as well as that of the bed first above it in the Broad Top field, was thoroughly consolidated long prior to the date of folding, for in those beds the fragments were rubbed one on the other until they became as thoroughly polished and lenticular as are the fragments of Utica slate in the Great valley further east. The Pocono coal near Christiansburg, Montgomery county, Virginia, was broken during the folding into irregular pieces, which are wedged together just as are the vastly greater fragments of Pocono sandstone in Wray's hill of Bedford county, Pennsylvania.

But the whole process of conversion must have been practically complete before the rocks were consolidated—indeed, before the coal was buried finally, the result of the pressure being to remove the water and marsh gas and to consolidate the coal. The extent of conversion would depend largely upon the length of time to which the peaty material had been exposed to percolation of water. That practically no further change takes place after burial and consolidation, is suggested by the conditions seen in the Laramie coals of New Mexico and Colorado. Within the Trinidad field the coal is anhydrous, rarely containing more than 2 per cent of water; but northward from Colorado Springs the coals of the same period have from 12 to 20 per cent, while along the Union Pacific railroad they have from 6 to 13 per cent in Wyoming and from 1.68 to 10.66 in Utah.* A similar contrast is found between the

* Marvine: Ann. Report of the U. S. Geol. and Geog. Survey of the Territories for 1873, pp. 112, 113.

almost hydrous coals of Iowa and Missouri and the anhydrous coal of Indian territory.

### The Writer's Hypothesis as to Origin of Coal-beds.

But we are not left altogether to suggestion in the effort to explain the origin of the Pennsylvania anthracite as resulting from continuous loss of marsh gas until the final burial and consolidation.

More than twenty years ago the writer, having discovered that the limestones of the Ohio Upper Coal Measures disappear at but a little way west from the Ohio river, was led to assert that the Coal Measures of the Appalachian basin "were not united to those of Indiana and Illinois at any time posterior to the Lower Coal Measures epoch and probably were always distinct." Studies made in the Ohio and West Virginia coal-fields led also to the conclusion that the lower coal-beds had been deposited as fringing marshes,* and that the coal-beds, for the most part, had their origin at the east. It is unnecessary to enter into the details of the theory of the origin of the Appalachian coal-beds presented by the writer in 1872† and amplified in later publications, as they do not concern the matter at issue here. It suffices that on purely stratigraphic grounds the conclusion was reached that the Coal Measures marsh had its origin at the east, and that it extended seaward after each period of accelerated subsidence, so forming a new coal-bed. According to this hypothesis one should find in the northeastern portion of the Appalachian basin not only a greater mass of coal than in any other part of the basin, but also a greater degree of conversion.

#### *APPLICATION OF THE HYPOTHESIS.*

*Thickness of Coal greatest in northeastern Portion of Appalachian Basin.*—Let the lower coal group be used first in making comparison of thicknesses in different parts of the basin.

The greatest thickness is found in the Southern and Middle anthracite fields and in the eastern portion of each. The variation in the Southern field is from 106 feet of coal ‡ at the extreme east to 18 feet at the extreme southwest. The average at the east is about 58 feet and for the middle about 53 feet. The thickness for the west end is taken from Taylor, but H. D. Rogers § thinks it too great. The Middle field does not extend so

* Stevenson cited by Newberry, Geol. of Ohio, 1874, vol. 2, part i, p. 169.

† Stevenson: Annals of Lyceum of Nat. Hist. of New York, 1873, vol. x, p. 252; Proc. Amer. Philos. Society, 1875, vol. xiv, p. 293; Second Geol. Survey of Pennsylvania, Rep. on Fayette and Westmoreland District, part ii, pp. 283–295.

‡ Ashburner: First Rep. of Progress in the Anthracite Coal-field, 1883, p. 45; Annual Report for 1885, pp. 330–339.

§ Rogers: Geol. of Pennsylvania, 1858, vol. ii, pp. 193-195.

far southwestward—that is, along the strike—as does the Southern. The thickness of coal varies from 52 to 53 feet in the eastern Middle, and from 58 to 40 feet in the western Middle, the last thickness being near Shamokin at the westerly end; * but in both the Southern and the Middle the Mammoth bed alone sometimes shows more than 100 feet of clear coal.† The Northern field in the westerly portion shows from 44 to 53 feet. The anthracite region, then, except in the extreme southerly prongs of the Southern field, shows an average thickness of from 40 to 60 feet of coal, the greater thickness being at the northeast.

Going southward or, better, along the trend, in this anthracite strip, the remarkable diminution in thickness noticed in the Southern field is found to be not local, for in Broad Top the thickness of coal does not exceed 14 or 15 feet,‡ and Professor White found the thickness on the east side of the Cumberland basin in West Virginia to be not more than 15 feet, with at least 2 feet of slate.§

In passing from the anthracite strip to the bituminous basins one finds no prong, like that of the Southern field, to show the continuous decrease in thickness; but that is not needed, for the decrease is sufficiently marked. In the first bituminous basin the thickness of the beds of the lower coal group, including all slates and partings, varies from 21 to 23 feet, the greater thickness being at the north; in the second basin the extreme is 19 feet near the Maryland line and 22 feet in Indiana county, while in the third basin and beyond, the thickness decreases until at the Ohio line it varies (all slates and partings being included) from 8 feet 6 inches to 13 feet 4 inches.‖

The lower barren group shows almost equally striking variations, for in the Southern field the interval between coal-beds E and H contains from 25 to 36 feet of coal, partings not included; the western Middle shows 39 feet at the eastern end and 20 at the western end, while in the Northern field this interval has from 17 to 27 feet. The Broad Top field shows not more than 5 feet. No detailed measurement was made by Professor White, owing to lack of exposures, on the east side of the Cumberland basin. Elsewhere in Pennsylvania and Ohio the amount of coal in this interval is extremely uncertain, the average in any single section seldom being more than 4 or 5 feet, though occasionally, as in Guernsey county of Ohio and Somerset county of Pennsylvania, a bed

* Ashburner: Annual Report for 1885, pp. 339, 341. 349, 351.

† Ashburner: First Report on Anthracite Coal-field, pp. 95, 103, 231, 232.

‡ Stevenson: Geol. of Bedford and Fulton Counties, 1882, pp. 60, 235, 259.

§ I. C. White: Proc. Amer. Phil. Society, vol. xix, pp. 440-441.

‖ These measurements are taken from the reports of the Second Geol. Surv. of Pennsylvania by White, Platt and Stevenson.

attains to local importance. The same contrast appears for these groups between the anthracite region of Pennsylvania and the bituminous areas of West Virginia, as Professor White has shown.*

Comparison of sections representing the upper coal group shows that the conditions were changing in the Southern field, for the upper beds are thin, seldom exceeding 2 or 3 feet; the same is true of the western Middle, but in the Northern the change is not so marked, the higher beds comparing very favorably with those of the lower barren group. The greatest thickness in the 400 feet taken as equivalent to the upper coal group of the bituminous areas is 26 to 29 feet in the Northern, 25 feet in the western Middle and 11 to 12 feet in the Southern anthracite field. In the Broad Top field the coal in all, counting partings, does not exceed 7 feet in a section of 260 feet. Tyson † found 36 feet of coal-beds in the Cumberland basin, but his description does not tell how much of this is coal. Professor White, however, found that in the 19 feet 8 inches of Pittsburg coal-bed there are but 14 feet 6 inches of coal. The Salisbury basin of the first bituminous area shows 16 feet of coal-beds in 200 feet of measures, but further westward the thicknesses are so variable that no estimates can be given that would be other than misleading. The variations of the Pittsburg bed, however, can be followed without difficulty. In the Cumberland basin it is 14 feet 6 inches; in the Salisbury basin, 10 feet; in the Ligonier basin, 8 feet; in the Connellsville or Coke basin it is from 6 to 9 feet; in the Greensburg, 6 to 7 feet 6 inches; in the Lisbon, 5 to 7 feet; but beyond that it rarely exceeds 5 feet, the extremes in Ohio along the river being 4 feet 6 inches to 5 feet, while in Guernsey county, on the northwestern outcrop of the bed, its thickness is but 4 feet 2 inches.‡ Professor Andrews has stated that at its last western outcrop the bed is not more than one foot thick. That is its thickness in the center of the Appalachian basin in southern West Virginia.

*Conversion greatest in the northeastern Portion of Appalachian Basin.*—It is evident that the conditions favoring accumulation of coal in beds lasted longer without interruption in the anthracite region than in any other portion of the Appalachian basin, for the amount of coal decreases westward and southward from that region. A comparison of thickness of beds shows a tendency to greater regularity in a northeasterly direction within the first and second bituminous basins; but it is unnecessary and it would be very tedious to enter into the details of this comparison.

* Bulletin no. 65, U. S. Geol. Survey.

† Tyson: Second Rep. to House of Delegates of Maryland, 1862, p. 46.

‡ These measurements are taken from the writer's reports on Pennsylvania and Ohio.

## Relation of increasing Thickness of Coal to decreasing Volatile in Pennsylvania.

Under such conditions one should expect the amount of volatile combustible matter to show marked decrease in the beds as they approach the old shorelines. This decrease is shown by the analyses. In the anthracite strip the ratios are as follows:

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|---|---|
| Cumberland basin* | 4.47 to 4.78 |
| Broad Top | 3.26 to 4.64 |
| Southern anthracite: | |
| Southeast prong (the longer) | 4.63 to 12.40 |
| Southwest prong | 8.91 to 11.30 |
| Main field | 11.64 to 23.27 |
| Western Middle | 19.87 to 24.00 |
| Eastern Middle | 25.53 to 30.35 |
| Northern | 19.33 to 19.92† |

Similar variations are found along the trend in the several bituminous basins. Thus in the first, the Clarion coal-bed shows from 2.94 to 4.84 near the Maryland line, but 5.48 to 6.09 in Lycoming county and 7.07 to 10.28 in Sullivan; the Brookville varies from 2.14 in Somerset to 4.13 and 6.93 in Sullivan. In the second basin, the Upper Freeport is 2.26 and 2.85 near the Maryland border, but becomes 3.96 to 4.48 in Lycoming; and the Clarion changes from 2.25 in Indiana to 3.88 in Tioga. But in the third basin it is not easy to make such comparisons, for the lower coals are buried deeply at the south and the higher coals extend but a little way northward from the Ohio and Conemaugh rivers. At the same time, it is clear that the variation becomes much less in this broad basin than it is in the basins nearer the anthracite region, which is precisely what we should expect. There is, however, a distinct decrease of volatile northward, as shown by the analyses of the Upper Freeport in Beaver, Armstrong and Clarion counties. The result of comparison is to show that the decrease of volatile is found along a line following the trend northward and along the line eastward to which Rogers referred.

## Conclusions.

The conditions, then, are—

First. A decided increase in thickness of the coal series eastward or, better, northeastward toward the anthracite region and a less marked increase northward in the bituminous basins.

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* Analyses of the Pittsburg coal-bed only are accessible.

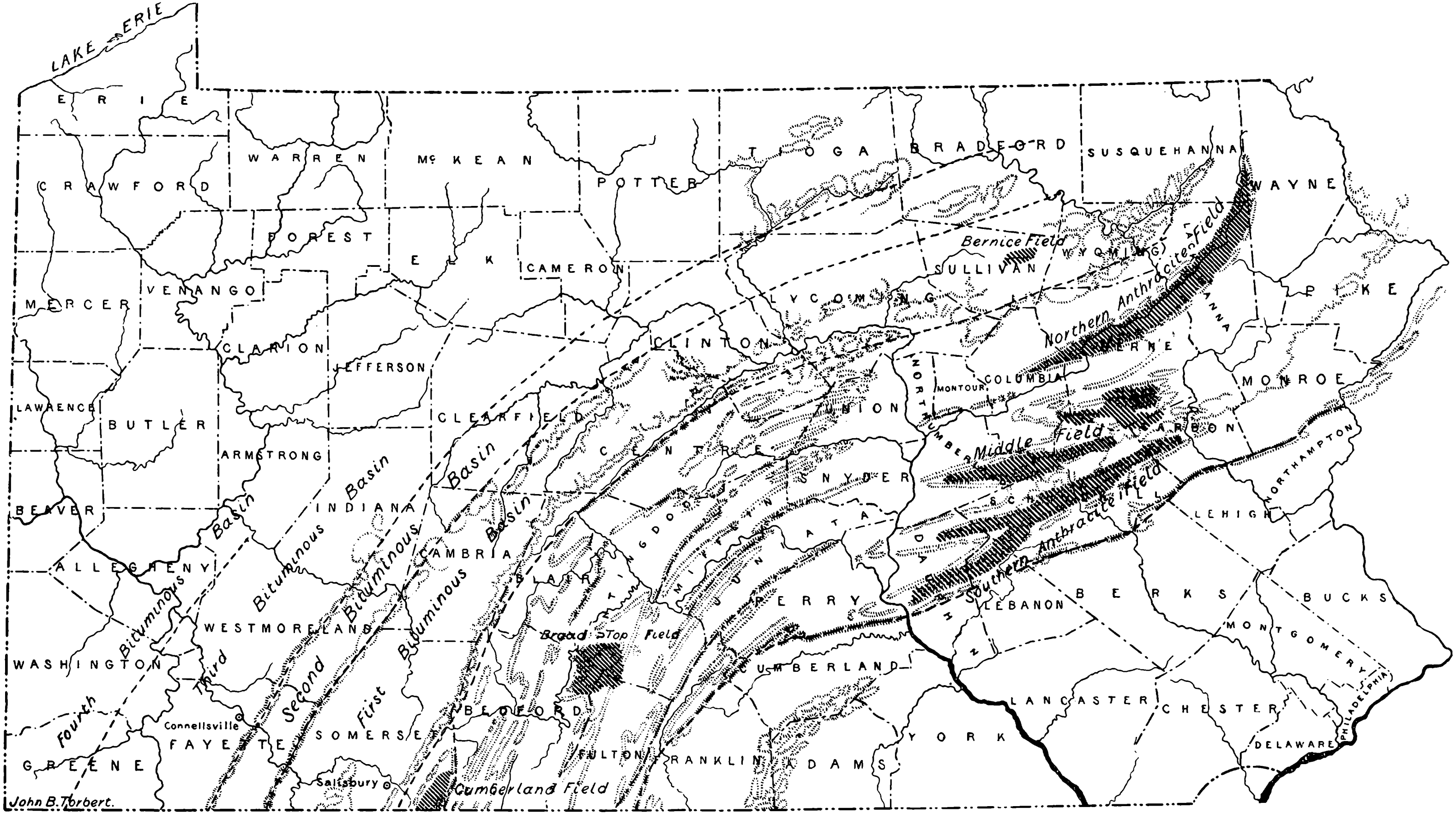
† These results of analyses are by Mr A. S. McCreath, except those from the southeast prong of the Southern field, which are taken from R. C. Taylor's Reports on Coal Lands of the Dauphin and Susquehanna Coal Company, 1840. Mr McCreath's analyses, for the most part, are in his second report, already quoted so often, and in the Annual Report for 1885.

Second. A decided decrease in volatile in the direction of increased thickness of coal, the decrease being comparatively gradual until near the anthracite fields.

Third. That this decrease is gradual even in the anthracite strip from the Cumberland basin to the semi-bituminous coals of the Southern anthracite field, where the rapid increase in thickncss of coal is accompanied by a rapid decrease in the volatile.

When, in 1877, the writer called the attention of his colleagues on the Second Geological Survey of Pennsylvania to the fact that the decrease in volatile is wholly without relation to increase or decrease of disturbance in the strata, he suggested that the variation was due to difference in conditions under which the coal had been formed in the several localities discussed—a sufficiently comprehensive hypothesis, but yielding in that respect to some others of later date. Now, however, there seems to be no good reason for any such suggestion; all that was needed was longer exposure to the process whereby ordinary bituminous coal was formed. In origin, the anthracite of Pennsylvania differs in nowise from the bituminous coal of the Appalachian basin; but because the great coal marsh, from which sprang the many beds, originated in the northeastern corner of the basin and extended thence on the advancing deltas, formed by streams descending from the Appalachian highlands, the time, during which the successive portions of the marsh would be exposed, would be less and less as the distance from the northeast and northern border of the basin increased, so that the extent of chemical change would decrease as the distance increased. It is therefore to be expected that in the northeastern corner, where the deltas were formed quickly after a subsidence and beyond which they advanced slowly, as shown by the changing type of rocks, the chemical change should have been almost complete, especially in the eastern Middle and eastern extremity of the Southern field, which occupy that part of the area in which the coal marsh, in almost every instance, appears to have thrust itself first upon the advancing delta.

It is quite possible that when detailed study of the anthracite areas in Arkansas and Russia have been made, the same explanation may be found applicable there also, and that the anthracite will be found near the old shoreline, whence the marsh advanced as new land was formed.




MAP OF PENNSYLVANIA SHOWING APPROXIMATE BOUNDARIES OF THE ANTHRACITE STRIP AND THE FIRST THREE BITUMINOUS BASINS.