ON THE ORIGIN OF THE PENNSYLVANIA ANTHRACITE.[1]

LONG ago, H. D. Rogers showed that the coal regions of Pennsylvania are divided into rudely longitudinal basins or troughs. In passing over the state northwestwardly, one crosses first the Archean area at the southeast, with its patches of Newark or Triassic; then the Great Valley, extending almost unbroken from the Hudson river to Alabama, and showing only Cambrian and Silurian with occasional patches of Devonian and Lower Carboniferous. Crossing the irregular northerly or northwesterly boundary of the valley, he reaches what, for the purpose of this discussion, may be termed the Anthracite Strip, which extends to the Alleghanies; this contains the Cumberland coal field of West Virginia and Maryland, the Broad Top field of southern Pennsylvania, and, still further northeast, the Southern, Middle and Northern Anthracite fields. The Bituminous coal basins, of which Rogers recognized six, are beyond the Alleghanies; the first, between the Alleghanies and Laurel Hill, is well defined near the Maryland line, but becomes less so northward, though it can be traced without difficulty into New York; the second, with Chestnut Hill as its westerly boundary, is the Ligonier Valley, which like the last can be followed into New York; the third, wider than the second, is less defined at the west, as its boundary on that side is an anticline passing but a little way east from Pittsburgh and producing insignificant topographical effects; the most important portion of the basin, in this connection, is the first sub-basin, known as the Connellsville coke basin, which follows the westerly foot of Chestnut Hill. The remaining bituminous basins, including the rest of

[1] Abstract of a paper read before the Geological Society of America, August, 1893.

Pennsylvania, northwestern West Virginia and eastern Ohio may be regarded as one, their details being unimportant in so far as the present study is concerned.

The trend of the anticlinal and synclinal axes is not N. N. E. and S. S. W. throughout, for one of the great curves of the Appalachian system is within Pennsylvania; the axis of the First Bituminous basin, for example, follows an almost W. S. W. direction until, in Clearfield county, midway in the state, its course is changed to S. S. W.; any topographical map of Pennsylvania illustrates the condition.

Interesting variations in the rate of dip are shown along a line drawn from Pittsburgh, Pa., southeastwardly across the coal area to the Cumberland field in Maryland, the contrast between the terminal conditions being very great. At Pittsburgh, the rate seldom exceeds one degree; in the Connellsville sub-basin it varies from four or six degrees along the lower portion of the trough to somewhat more than ten degrees on the side of Chestnut Hill, the increase in rate thus far being quite regular. No further increase is found in crossing the second and first basins, the dip even on the easterly side of the Alleghanies rarely exceeding twelve degrees. But the extent of disturbance becomes markedly greater at once after the Anthracite Strip has been reached, for there dips of 20, 40, 70 and 80 degrees are seen.

The conditions observed along this line are not representative of those throughout the coal area, for in all the basins, even in those of the Anthracite Strip, the degree of disturbance eventually becomes less along the trend northwardly. The existence of the anthracite fields themselves is due to a remarkable decrease in violence of the disturbance, a dying away northward of anticlines, permitting formation of broad synclines, which in their turn act as do the canoe synclines of the bituminous areas, which, rising, send the lower formations into the air. Southwardly, the condition is markedly different; for though the extent of disturbance, except in the Anthracite Strip, decreases rapidly, the decrease is due to depression of anticlines and not, as at the north, to the general elevation of the synclines and their passage into the New York plateau.

Analyses of coal samples, taken from the Pittsburgh bed in the several basins, show a progressive decrease in the proportion of volatile, combustible matter toward the east or southeast, a fact which early attracted the attention of H. D. Rogers, and which has possessed much interest for geologists ever since. Analyses made for the Second Pennsylvania Survey prove the same condition in the lower coals. Mr. Winslow's studies of the Arkansas coals show a similar tendency to decrease in the same direction; and Murchison discovered a like condition in the Donetz anthracite field of southern Russia.

H. D. Rogers,[1] in 1842, announced to the Association of American Geologists the law of gradation, as he understood it, which 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 caking coal." Finding, as he believed, that the volatile matter in the coal augments westwardly, precisely as the flexures diminish, he attributed the variation to the influence of steam and other intensely heated gases escaping through crevices necessarily produced during the permanent bending of the strata. Under such conditions, the coal throughout the eastern basins, the more disturbed, would discharge more or less of the volatile constituents during the violent earthquake action, whereas the more western beds, less disturbed, would be less debituminized.

J. J. Stevenson,[2] in 1877, showed that the variations in volatile exhibited by the Pittsburgh coal bed along the southeast and northwest line bear no relation whatever to increase or decrease of stratigraphical disturbance, and suggested that the variations are due to difference of conditions under which the coal was formed.

[1] ROGERS: Reps. of the 1st, 2d and 3rd meetings of the Association of American Geologists and Naturalists. 1843, pp. 470 et seq.

[2] STEVENSON: 2d Geol. Surv. of Penn., Rep. of Progress on the Fayette and Westmoreland Dist. Pt. I. pp. 61, et seq.

J. P. Lesley,[1] in 1879, offered some interesting suggestions. If the anthracite be metamorphosed bituminous coal, the change might be caused by exposure to comparatively high temperature at a great depth below the surface. As the temperature increaess one degree Fahrenheit for each fifty feet, more or less, of descent, the coal under cover of a great thickness of rock could not fail to be deprived of its volatile matter. He compares the composition of coal from the highest available bed in western Pennsylvania with that from the lowest bed in the same region, and finds less volatile in that from the lower bed. As all of the Paleozoic rocks thicken eastwardly, there must have been a much greater pile of Coal Measures in the anthracite region than in the bituminous areas, though erosion has removed the proof. Necessarily then the coals of the anthracite region should show less volatile than do those of the bituminous area, where the pile of rocks was less thick.

Professor Lesley suggests also that if one desire to explain the origin of the anthracite by oxidation in preference to metamorphism, the conditions afford basis for such explanation, since in the anthracite region the rocks are not only broken and shattered by the folding, but they are made up largely of sand and gravel, so that the conditions are such as to favor percolation of water, evaporation, and consequently oxidation; whereas, in the undisturbed bituminous areas, clayey beds are in large proportion and lute down the buried coals so as to prevent percolation and the rest.

There is no possible room for doubt that bituminous coal can be converted into anthracite by heat. The Galisteo, Elk Mountain and other localities within the United States, the Hesse Cassel and New Zealand areas in foreign lands, prove beyond dispute that, under proper conditions, contact with molten rocks suffices for the conversion. But no question of such conversion is at issue here, for in Pennsylvania no dikes occur near enough to the anthracite areas, or large enough even if near enough, to

[1] LESLEY: In McCreath, 2d Geol. Surv. of Penn., 2d Rep. of Progress in the Laboratory, etc. 1879, pp. 153, et seq.

produce by contact the extensive tracts of anthracite still remaining in the state.

Professor Rogers's explanation seems to have been based throughout on a misunderstanding of the conditions. There is no good reason for supposing that the Appalachian Revolution was produced by violent disturbances such as those imagined by Professor Rogers; on the contrary, there appear to be the best of reasons for supposing the final folding to be but an acceleration of the process which had gone on, perhaps not continuously, from a very early period. The slowness of the process even at the close is suggested by the courses of the main waterways. The fundamental error, however, respects the relation of dip and volatile. The dip along the line selected by Professor Rogers, that from Pittsburgh to the Cumberland coal field in Maryland, does indeed show great changes, but as already stated they are not gradual. Let the condition be recalled. At Pittsburgh, the dip is from $\frac{1}{2}°$ to $1°$; in the Coke basin, 30 miles away, it is from $4°-6°$ at the lower portion of the trough, to $10°-12°$ higher up the side of the anticline; in the Salisbury basin, 34 miles further, the dip is the same or less, there being practically no change in the interval from the Coke basin; and no further change is found until one has passed the Alleghanies and entered the Anthracite Strip, where a marvelous change is seen, for the dip is sometimes vertical. Now despite all this, the decrease in volatile, as shown by the Pittsburgh coal bed along this line, is almost regular; thus at Pittsburgh, the average analysis shows of volatile 40.7 per cent. (ash and water being ignored in the calculation); at Connellsville, 33.8, a decrease of 6.9 in 30 miles with an increase of dip from $1°$ to say $8°$; at Salisbury, the volatile is only 23.3, a decrease in 34 miles of 10.5 with no change whatever in rate or type of folding; while in the Cumberland basin, about 15 miles further, the volatile is 18.8, a decrease of only 4.5, despite the complete change in type and remarkable increase in extent of disturbance; and this last field is within the anthracite strip itself, is in proper position, along the trend, to be the continuation of the Northern Anthracite field.

Professor Rogers's error in this matter prevented him from observing that the volatile decreases northwardly along the trend in the several basins even more notably than along the line chosen by him. The hardest anthracite is not in the Southern field, where the folding is most complicated, but in the Eastern Middle. The Southern Anthracite field shows all gradations from bituminous coal at its southern extremity to hard, dry anthracite at its northerly end.

Professor Lesley's suggestion that the Coal Measures attained to much greater thickness in the anthracite region than in the bituminous areas hardly accords with the facts as now known, many of them published since he offered his suggestions. It is altogether certain now that the lower three divisions of the Coal Measures in Pennsylvania, the Pottsville, the Lower Coal Group and the Lower Barren Group, do not show any variations which would justify one in basing a theory upon them; and it is much more than probable that the Upper Coal Group and the Permo-Carboniferous attain their greatest thickness in the north central portion of the Appalachian basin, and that they diminish in thickness westwardly, northwardly and eastwardly from southwestern Pennsylvania, as abundantly appears from the measurements made by I. C. White and by the writer in Pennsylvania, Ohio and West Virginia. In any event, the thickness of the mass in northeastern Pennsylvania was small in comparison with the thickness of the series in Virginia, West Virginia and Kentucky, on the southeastern edge of the Appalachian basin; yet in those states the coal shows no tendency to be anthracite; that of the Imboden coal bed of Virginia and Kentucky, almost at the base of the Lower Coal Group of Pennsylvania, is richly bituminous.

Nor does the theory that anthracite is bituminous coal converted by heat due to mechanical force, commend itself in this connection. The crushed and polished coal of the Broad Top field is bituminous, whereas the uncrushed coal of the Northern field in the same strip is anthracite. The Quinnimont coal, in the gently flexed New River district of West Virginia, has practically the same amount of volatile as is found in the same coal near Pocahontas, Virginia, close to the great fault of Abbs valley.

But it is unnecessary to look to metamorphism for an explanation of the Pennsylvania anthracite; at best, metamorphism is an unsatisfactory explanation, because it is difficult to find evidence that metamorphosing agencies have been in operation there. One does not think of metamorphism when he finds in the coal of a given bed a variation of five or ten per cent. of volatile within short distances, or even when he finds, as in Sullivan county of Pennsylvania, anthracite in one bench and bituminous in another bench at the same opening.

As was shown long ago by Bischof and others, anthracite can be produced simply by continuation of the process whereby vegetable matter is converted into bituminous coal—by continued formation of carburetted hydrogen until the hydrogen has been removed. Professor Lesley's ingenious suggestion that this can go on more readily in the anthracite region than in the bituminous areas, because of the difference in composition and condition of the rocks, hardly suffices. If only the extremes of the series were to be accounted for, and if all were confined to the anthracite strip, it might be regarded as sufficient; but all gradations from rich caking coal to anthracite occur in the First bituminous basin, where the rocks are comparatively undisturbed and consist largely of argillaceous shale. Moreover, in a single colliery within the Southern Anthracite field, one bench of the Mammoth bed yields a more than semi-bituminous coal, while from another is obtained almost the driest of anthracite. But an equally serious objection is, that the coal must have been converted finally before complete entombment, so that the effect of the pressure would be to remove water and to solidify the coal. The hardening of the coal was complete in the Broad Top field before the Appalachian revolution occurred, for in the final folding the coal, as shown in some mines, was broken into lenticular and polished fragments precisely like those of the Utica shale within the disturbed valley east from the Anthracite Strip. The Laramie coals on the western side of the great plains in New Mexico, Colorado and Wyoming can hardly have undergone any material change since the final burial; otherwise the strange variations in composition would be inexplicable, the difference in condition as to character of rocks and degree of disturbance being insufficient.

Twenty years ago the writer, while connected with the Ohio Survey, reached the conclusion that the marsh, from which sprang the several beds of the Upper Coal group, originated at the east; two years later he was led to assert that the coal beds were formed as fringes along the shore of the Appalachian basin. If this be the true doctrine, there should be found in northeastern Pennsylvania,

First. A vastly greater thickness of coal than in other portions of the basin.

Second. A greater advance in the conversion of vegetable matter into coal, owing to the longer period elapsing prior to entombment.

As to the first condition, there can be no doubt. A comparison of the several divisions of the Coal Measures as they appear in the several basins of the state illustrates it well; but such a comparison would be tedious here, and only the Lower Coal group of the Pennsylvania series is used (that lying between the Pottsville conglomerate below and the Mahoning sandstone above).

In the Anthracite Strip this group shows in the several fields, from south to north, as follows:

Cumberland Field, bituminous,	13′
Broad Top Field, bituminous,	14′–15′
Southern Anthracite, bituminous to anthracite,	18′–60′
Middle and Northern Anthracite, anthracite,	40′–58′

The thicknesses in the Bituminous basins are:

First,	21′–23′
Second,	19′–22′
Fifth,	8′6″–13′4″

The thicknesses, as given for the Anthracite Strip, are those of coal exclusive of slate and other partings, but those for the Bituminous areas include the slates and other partings, so that the actual amount of coal is less than the figures indicate. It is sufficiently clear that the conditions favoring the accumulation of coal in beds continued longer without interruption in the anthracite region than they did elsewhere within the Appalachian basin; for the contrast is equally marked, when the anthracite region is compared with the Virginias or Kentucky further south-westward. The process of conversion also continued longer without interruption, as the chemical analyses show.[1] Thus, in the Anthracite Strip, one finds:

Cumberland Field (only the Pittsburgh),	4.47– 4.78	Coal, 13′
Broad Top Field, - - -	3.26– 4.64	Coal, 14′
Southern Anthracite Field,		
Southern prong, - -	4.36–12.40	Coal, 18′–30′
Main Field, - - -	11.64–23.27	Coal, 30′–60′
Western Middle Field, -	19.87–24	Coal, 40′–58′
Eastern Middle Field, - -	25.53–30.35	Coal, 52′–53′
Northern Field, - -	19.37–19.92	Coal, 44′–53′

The anthracite analyses are commercial, samples chosen from carload lots. Very much higher ratios are obtained by sampling single benches.

The First and Second Bituminous basins show a similar change along the line of trend, the amount of volatile decreasing northwardly as one approaches the old shore line.[2] Thus, in the First, the Clarion coal bed shows from 2.94 to 4.84 near the Maryland line, but from 7.07 to 10.28 in Sullivan county, where is its last exposure at the north. In the Second basin, the Upper Freeport coal shows 2.26 to 2.85 near the Maryland border, but 3.96 to 4.48 at the last northerly exposure, in Lycoming county. The variations in the Third and other basins are less, as one

[1] The figures here given are the ratios between the Fixed Carbon and the Volatile Combustible, the ash and water being ignored; the more volatile, the smaller the ratio.

[2] Some curious variations, apparently contradictory of the statement here made, occur in the analyses. These will be discussed and their interest shown by the writer in a review of theories respecting the origin of coal beds, which is now in course of preparation.

should expect, for according to the supposition, the conditions at that distance from the old shore line should vary little anywhere.

So one finds,

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

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 Field to the semi-bituminous coals of the Southern Anthracite field, where the rapid increase in thickness is accompanied by a rapid decrease in the volatile.

When, in 1877, the writer called the attention of his colleagues on the Pennsylvania Survey 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 this 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 coal of Pennsylvania differs in no wise from the bituminous coal of other parts of the Appalachian basin; but because the great marsh, from which sprang the many beds, originated in the northeastern corner of the basin and extended thence again and again 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 northeastern 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 subsidence was checked, and beyond which they advanced slowly, as shown by changing type of rocks, the chemical change should have been almost complete, especially in the eastern Middle and the 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 shore line, whence the marsh advanced as new land was formed.

JOHN J. STEVENSON.