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THE MANNINGTON OIL FIELD AND THE HISTORY OF ITS DEVELOPMENT.

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THE FIELD.

Location and general Features.—The Mannington oil field is situated in Marion county, West Virginia, on the main line of the Baltimore and Ohio railway. It is an extension of the Mount Morris (Pennsylvania) field, which begins just north of the West Virginia state line and trends in a belt of varying width southwestward across Marion and Monongalia counties to the edge of Harrison county. Dolls run, Pedlars run, Jakes run, Fairview and Mods run are centers of development along the belt, which as now defined is from half a mile to three miles wide and about 35 miles long.

The cross section on the accompanying map (plate 6) shows that the oil belt in question is found on the western slope of the Indiana anticline, and is from 15 to 20 miles distant from the great axis of Chestnut ridge. The dip is northwestward, and varies from 150 feet per mile at Mount Morris to 50 feet at Mannington. The belt is thrown westward in southern

Monongalia by the development of a new anticline which elevates the oil rock into the gas belt along its previous trend, and thus causes the oil level to veer westward, at the same time reducing the rate of dip and consequently broadening the oil belt in that region, as shown by the map.

Source of the Hydrocarbons.—The oil is found in the Pocono sandstone (Vespertine, X, etc, of Rogers) or lowest member of the Carboniferous system, its geological equivalent being the Logan sandstone of Ohio, the Shenango and Sharpsville sandstones of Pennsylvania, and the Marshall group of Michigan. This geological horizon has furnished oil at several localities in this country: the "Slippery rock" and "Manifold" oil sands of Pennsylvania, the "Mecca" sand of Ohio, and the main sand at Burning springs and Volcano, West Virginia, all belonging to the Pocono beds. It was from this same horizon that natural gas was obtained in the Kanawha valley fifty years ago, and there first utilized for manufacturing purposes. The Warfield gas wells of Kentucky are in this sand, and it also furnishes oil at many localities in that state, while the asphalt deposits (residua of evaporated petroleum) of Alabama occur in the same series. Hence it will be perceived that this horizon is one which holds hydrocarbons over a wide area, just like the older Catskill (Venango oil sands) and upper Chemung beds (Bradford and Warren sands) below.

This oil rock was several years ago dubbed the "Big Injun" sand by some facetious driller in Washington county, Pennsylvania, where it is about 250 feet thick and very hard, thus rendering the progress of the drill through it quite slow and suggesting the name which it has ever since maintained in oil parlance, viz, the "Big Injun" sand. It is also sometimes called the "Manifold" sand, from the farm in Washington county on which was obtained the only paying well in that county at this horizon, out of the hundreds and thousands that have been drilled through it, though the name "Mount Morris" sand is more appropriate, since it has proven more productive of oil in the Mount Morris-Mannington field than anywhere else.

The oil and gas are not disseminated uniformly through the sand rock but occur in "pay streaks" at 60 to 135 feet below the top of the Pocono sandstone, the richest and main horizon being found at 85 to 110 feet. At about 20 feet in the sand there is a layer which frequently furnishes a small flow of gas, but has never yet produced any oil. Then at 60 to 75 feet the "first pay" is usually obtained, and at 85 to 110 the "second pay;" while a "third pay" may be found at 120 to 135 feet. These "pay streaks" are merely coarser and more open layers of sand in which the oil, gas, or water, as the case may be, finds a good receptacle.

The texture of this sand is not coarse and pebbly like the Catskill conglomerate of the Venango sand group, and hence its oil wells are never so large as those from the latter beds, but they are on that account the more lasting. The wells in the "Mount Morris" or "Big Injun" sand produce from 5 to 500 barrels daily, after they have been flowing for a period of thirty days, though some have been known to start off at the rate of 50 barrels an hour when first struck.

The oil is of a beautiful amber color and compares favorably with the best of that produced from "white sand" territory. Its gravity is 48° to 50° as the oil issues fresh from the wells, but this usually falls to 45° by the time it reaches the main pipe line station and starts on its journey through the great pumps of the National Transit company to tide water at Philadelphia.

THE STRATIGRAPHY.

The Mount Morris Section.—The following record of the Core well number 2, near Mount Morris, kept by Mr. John Garber, contractor, exhibits the geological relations of this oil sand to the overlying beds of the Carboniferous system in that region:

	Feet.	Feet.
Permian or Dunkard Creek series:		
Conductor (clay)	21 to 21	
Slate	104 to 125	170
Sandstone, Waynesburg	45 to 170	
Upper Coal Measures:		
Coal, Waynesburg	10 to 180	
Limestone and shales	120 to 300	
Sandstone	25 to 325	
Limestone (Great limestone)	85 to 410	355
Black slate	10 to 420	
Coal, Sewickley	10 to 430	
Limestone, Sewickley and Redstone	85 to 515	
Coal, Pittsburg	10 to 525	
Barren Measures or Elk River series:		
Slate (cased at 531 feet)	70 to 595	
Sandstone, Connellsville	55 to 650	
Red shale	35 to 685	
Sandstone	15 to 700	
Red shale	10 to 710	
Blue shale	25 to 735	
Sandstone, Morgantown (salt water at 760 to 785 feet)	55 to 790	
Blue slate	40 to 830	525
Red and blue shale (Crinoidal limestone horizon; caves badly and causes much trouble in drilling)	20 to 850	
Limestone and hard beds	80 to 930	
Red slate	5 to 935	
Sandstone, Upper Mahoning	25 to 960	
Dark slate	60 to 1020	
Sandstone, Lower Mahoning	30 to 1050	
Lower Coal Measures:		
Slate, light gray	60 to 1110	
Sandstone, Freeport	80 to 1190	
Dark slate	25 to 1215	
Limestone, Johnstown	40 to 1255	310
Dark slate	40 to 1295	
Sandstone, hard	5 to 1300	
Slate	60 to 1360	

Pottsville conglomerate:		
"Salt sand," part of XII (water at 1,442 feet)	150 to 1510	210
Slate (cased at 1,515 feet)	10 to 1520	
Limestone (?)	20 to 1540	
Slate	10 to 1550	
Dark pebbly sand	20 to 1570	
Mauch Chunk shale:		
Light-colored sandstone	95 to 1665	178
Limestone, hard	22 to 1687	
Red shale	13 to 1700	
Dark slate	45 to 1745	
Red shale	3 to 1748	
Limestone, "Mountain" or "Greenbrier"	56 to 1804	157
"Big Injun" or Mount Morris sand, with oil from 1,890 to 1,912 feet	101 to 1905	

The Mannington Section.—In the Hamilton test well (number 1) at Mannington also the record was kept by Mr. Garber, and reads as follows:

	Feet.	Feet.
Permian or Dunkard Creek series:		
Conductor (soil)	15 to 15	90
Coal, Waynesburg "A"	1 to 16	
Slate	14 to 30	
Blue sand, Waynesburg	35 to 65	
Slate (Waynesburg coal at 78 feet, but not noted)	25 to 90	
Upper Coal Measures:		
Sandstone, Browntown	30 to 120	392
Limestone	40 to 160	
Slate	35 to 195	
Limestone interstratified with thin shales	142 to 337	
Slate	8 to 345	
Coal, Sewickley	12 to 357	
Slate	35 to 392	
Limestone	48 to 440	
Dark slate	19 to 459	
Coal, Pittsburg	11 to 470	
Barren Measures or Elk River series:		
Slate	25 to 495	607
Limestone, hard	40 to 535	
Sandstone, Connellsville	35 to 570	
Slate	23 to 593	
Sandstone, hard	4 to 597	
Red shale	6 to 603	
Variegated shales	87 to 690	
Red shale	10 to 700	
Limestone (shaly), Crinoidal	45 to 745	
Coal, Crinoidal	5 to 750	
Blue slate	25 to 775	
Limestone	10 to 785	
Red shale	13 to 798	
Limestone and shales	26 to 824	
Sandstone, dark	20 to 844	
Slate, dark	31 to 875	
Sandstone, Upper Mahoning (some gas and water)	45 to 920	
Slate, gray (caving material)	65 to 985	
Sandstone, Lower Mahoning	92 to 1077	

Lower Coal Measures:		
Slate	93 to 1170	
Sandstone, hard	15 to 1185	
Sandy shales and slate	45 to 1230	
Trace of coal (Kittanning Upper coal?)		
Black slate	20 to 1250	293
Sandstone, very hard	27 to 1277	
Coal and slate, Lower Kittanning	17 to 1294	
Limestone and slate	21 to 1315	
Hard sandy shales, and slate	55 to 1370	
Pottsville conglomerate:		
White pebbly sandstone ("salt sand;" big flow of salt water at 1,385 feet)	117 to 1487	
Dark slate	31 to 1518	
Dark pebbly sandstone	15 to 1533	200
Sandy beds	37 to 1570	
Trace of coal, base of number XII		
Mauch Chunk shale:		
Light-colored slate	30 to 1600	
Red shale	78 to 1678	141
Limestone, slaty (cased at 1,680 feet)	28 to 1706	
Red slate	5 to 1711	
Limestone, "Mountain" or "Greenbrier"	92 to 1803	
"Big Injun" (Mount Morris) oil sand, composed of—		
(*a*) Gray sand (gas at 1,815 feet) 37		
(*b*) Cream-colored limestone 17		
(*c*) Dark sand 10	72 to 1875	219
(*d*) Gray sand with oil at base 8		
(*e*) Bluish gray sand (with more oil at 1,885 feet and some water at 1,910 feet)	55 to 1930	

The bottom of the Waynesburg coal should have been found in this well at about 78 feet from the surface.

The Fairview Section.—Near Fairview, 10 miles northeast of Mannington, the measures exhibit the following structure, as shown by the record of the Brice Wallace well number 1, given me by Mr. John Worthington, of the South Penn oil company:

	Feet.	Feet.
Conductor	12 to 12	
Gray slate	30 to 42	
Coal, Waynesburg "A"	4 to 46	137
Sandstone, Waynesburg	87 to 133	
Slate	4 to 137	
Upper Coal Measures:		
Coal, Waynesburg	7 to 141	
Slate	5 to 149	
White sandstone, Browntown	40 to 189	
Coal, Little Waynesburg	6 to 195	
Limestone	39 to 234	
Slate and sandy beds	50 to 284	
Limestone	36 to 320	
Slate and limestone	60 to 380	390
White sandstone, Sewickley	40 to 420	
Coal, Sewickley	10 to 430	
Slate, soft	25 to 455	
Limestone, hard	35 to 490	
Slate	30 to 520	
Coal, Pittsburg	14 to 534	

Barren Measures or Elk River series:			
Slate, white		31 to 565	
Limestone		40 to 605	
Slate, white		15 to 620	
Red shale		25 to 645	
Light sandy beds		50 to 695	
Red and gray shales		165 to 860	
Limestone		15 to 875	556
Red and gray shales		40 to 915	
Sandstone		25 to 940	
Coal (Masontown) and white slate		30 to 970	
Sandstone, hard, Upper Mahoning		35 to 1005	
Slate, dark		45 to 1050	
Sandstone, Lower Mahoning		40 to 1090	
Lower Coal Measures:			
Coal (Upper Freeport) and slate		20 to 1110	
Dark slate and sandstone		160 to 1270	270
Sandstone		30 to 1300	
Slate and sandy beds		60 to 1360	
Pottsville conglomerate:			
Sandstone (top of XII, Homewood)		50 to 1410	
Slate and sandy beds		69 to 1479	255
"Salt sand" (salt water at 1,525 feet)		136 to 1615	
Mauch Chunk shale:			
Red beds		140 to 1755	165
Slate, dark		25 to 1780	
Limestone, "Mountain" or "Greenbrier"		70 to 1850	
"Big Injun" (Mount Morris) sand, composed of—			
(*a*) Gray sand	65		
(*b*) Limestone	7		
(*c*) Sand, gray (some gas; "first pay")	20		
(*d*) Sand, gray (heavy gas; "second and third pays")	30	142 to 1992	219
(*e*) Sandstone (oil show in bottom)	13		
(*f*) Sand	7		
Slate to bottom of well		5 to 1999	

General Features.—By reference to the details of these records it will be observed that the Upper Coal Measures (XV), Barren Measures (XIV), Lower Coal Measures (XIII), Pottsville conglomerate (XII), and the Mauch Chunk shale and Mountain limestone (XI) are all well represented, and that the latter series rests immediately on top of the Mount Morris oil sand, which corresponds to formation X of Rogers, or the Pocono sandstone of Lesley.

Another interesting fact will also be observed, viz, that the interval from the Waynesburg coal to the top of the oil sand is 1,624 feet at Mount Morris, 1,706 feet at Fairview, and 1,725 feet at Mannington, thus showing a progressive increase in this interval from Mount Morris to Mannington of about 100 feet. This condition of affairs, as will be seen hereafter, plays a very important part in determining the exact course of the Mount Morris oil field when traced southwestward.

Development of the "Anticlinal Theory."

The Mannington oil field was developed by myself and associates, and as its location was made from purely scientific deductions illustrative of certain theories concerning oil and gas accumulation which I have taught for several years, a brief history of these theories and their application in the discovery of the Mannington field may not be without interest to geologists; and this must excuse much that is personal to myself in connection therewith.

As is well known, it was formerly a popular saying among practical oil men that "Geology has never filled an oil tank;" and to such a low estate had oil geology fallen that a prominent producer of oil and gas, disgusted with geology and geologists, was once heard remark that if he wanted to make sure of a dry hole he would employ a geologist to select the location. It has been my pleasant task during the last eight years to assist in removing this stigma from our profession, so that with the able and valuable assistance of Ohio's distinguished geologist, Professor Orton, Dr. Phinney, of Indiana, and others the battle against popular as well as scientific prejudice has been fought and won and this long standing reproach to geology in great part removed. The battle was opened by the publication of a paper in "Science" of June 26, 1885, entitled "The Geology of Natural Gas," by I. C. White.*

As geologists are aware, Hunt, Andrews, Minshall, Newberry, and Stevenson had all previously recognized some of the factors of oil and gas accumulation, but the paper in question contained the first clear exposition of what has been termed the "anticlinal theory" of oil and gas. As therein stated, I was led to the discovery of the laws of gas, oil and water accumulation through a remark by Mr. William A. Earseman, a practical oil operator of many years' experience, and now general superintendent of the South Penn oil company, one of the Standard oil company's most successful concerns. Mr. Earseman believed, in spite of the disrepute under which geology rested with practical oil and gas operators, that it could, if rightly applied, render them valuable service. He believed this so thoroughly that he induced Captain J. J. Vandergrift, president of the Forest oil company, to engage my services in June, 1883, for a general study and investigation of the subject, the results of which were embodied in the paper to which reference has been made. The propositions formulated then for the first time in any scientific publication provoked a discussion of the general subject of oil and gas accumulation, and as these letters and papers of mine are scattered through several journals which

* Reprinted in the Appendix, ante, pp. 204–206.

geologists generally have not read, and as they mark a new and important epoch in the history of gas and oil geology, and are therefore worthy of being preserved to geological literature in a more permanent form than they have heretofore had, I shall append to this paper a fairly complete history of that discussion so far as my own part in it was concerned, the same being compiled from the pages of *Science*, *The Petroleum Age* and the *American Manufacturer*, in which journals my contributions to this subject were originally published.

The essential principles involved in the paper and discussions referred to, as embodied in the "anticlinal theory," have been very forcibly and graphically set forth by Professor Edward Orton, whose philosophic mind and skillful hand have grappled with and raveled so many tangled threads of geologic history. Grasping at once the truth of the "anticlinal theory," he applied its principles in a striking and beautiful way to the explanation of the oil and gas deposits of Ohio. Expressed in his words, *relief* or *structure* is the essential element in the accumulation of large quantities of either oil or gas, for if the rocks lie nearly horizontal over a wide area we find, when we bore through them, "A little oil, a little gas, a little water, a little of everything, and not much of anything;" while if the rock reservoirs be tilted considerably, so that the small quantities of oil, gas, and water in all sedimentary beds can rearrange themselves within the rocks in the order of their specific gravities, then and then only can commercial quantities of each accumulate, provided the reservoir and cover are good. The anticlinal waves which traverse the great Appalachian plateau westward from the Alleghanies and practically parallel to these mountains present just such relief as the theory requires in the New York, Pennsylvania, southern Ohio, and West Virginia oil and gas fields, while the more ancient flexures in northern Ohio and Indiana account for the large accumulations of oil and gas in the Trenton limestone of those states. The Florence (Colorado) and other oil fields in the far western states and territories have this tilted rock structure, and the same relief is plain in the Canadian oil and gas fields, according to Selwyn; while Tschernyschew, Sjögren, and other geologists who have studied the foreign oil fields, report an identical geological structure there.

This theory, so simple and consonant with well known physical laws, as well as so harmonious with the facts of geology, was heartily welcomed by most of the oil and gas operators, and by nearly all geologists that have given any thought to the matter, as a satisfactory solution of the geologic problem connected with oil and gas accumulation. A few have attempted to relegate the great principle of relief to a subordinate position, but the facts have pointed so conclusively in the other direction that opposition has been silenced at least, whether convinced or otherwise.

Guided by this theory I located in 1884 the important gas and oil field near Washington, Pennsylvania; also the Grapeville gas field along that great arch of the same name in Westmoreland county; and the Belle Vernon field on the Monongahela river. On the same theory I located and mapped out, for Mr. J. M. Guffey, the celebrated Taylortown oil field of Washington county months before the drill demonstrated the truth of my conclusions. And right here on this Mannington-Mount Morris belt a derrick was built to bore for oil on one of my locations at Fairview more than five years before the drill finally proved that my location was immediately over one of the richest pools of oil in the country, and before the drill had shown that there was any oil in this portion of West Virginia. These are only a few of the positive fruits of the theory to which we can point; the negative results in condemning immense areas for both oil and gas being even more important in preventing unnecessary expenditure and waste of capital where a search for either gas or oil would have certainly been in vain.

An important corollary, drawn from the "anticlinal theory" of gas and oil, and announced as probably true in my article in *The Petroleum Age* for March, 1886, was that the pressure under which the oil and gas in any rock or field are found is of artesian origin; or in other words that the initial pressure in any oil or gas field is measured by the pressure of a column of water equal in height to that which rises from the same rock when water is struck instead of oil or gas. This was announced as the most probable theory in the paper referred to, and Professor Orton has since* demonstrated the theory to be true in Ohio with reference to the gas pressures in the Trenton limestone.

The problem of proving that the oil and gas pressures found in the various sands of Pennsylvania and West Virginia are due to artesian pressure is not so simple as in Ohio, since the one rock there emerges from the earth at the level of lake Superior, while the several sand horizons of West Virginia and Pennsylvania come up in many regions of the country from the base of the Alleghanies westward to the Ohio river and northward to lake Erie, so that one can never be certain as to the exact datum plane from which to measure the top of the water column which gives origin to pressure; and therefore while the observations prove the general truth of the theory of artesian pressure for the "white sand" rocks of Pennsylvania and West Virginia, they are not so complete and demonstrative as in Ohio and Indiana.

The gradual increase of pressure with depth is strikingly shown in the following series:

* Bull. Geol. Soc. Am., vol. 1, 1889, pp. 87–94.

	Feet below tide.	Lbs. per sq. in.
Gas in Pottsville conglomerate at Mannington	200–300	350–400
Gas in Mount Morris sand at Mount Morris and Mannington	700	500–550
Gas in Mount Morris sand at Blacksville	800	600 +
Gas in Mount Morris sand at Harrisville (West Virginia)	1,000	680 +
Gas in Gordon sand near Pittsburg	1,000	800 +
Gas in Gordon sand near Waynesburg	2,000	1,300 +

The same story is told by any other set of observations, viz, that for any particular stratum the amount of pressure its gas develops is directly proportional to its depth in about the same ratio which a column of water increases pressure with increasing length.

Since the column of salt water never rises to the surface through southwestern Pennsylvania and West Virginia, and since it is almost impossible to get the oil drillers to make accurate measurements down to the top of the water in any particular case, exact calculations as to what the theoretical pressure should be have not been made, though from close estimates by cable measurement of the height of the column of water it is known that the observed pressure in all of the "white sand" oil and gas rocks of West Virginia and southwestern Pennsylvania corresponds very closely with what it should be on the hypothesis of artesian origin. Hence these facts have precluded any other interpretation, and this origin for the gas and oil pressure has entered into all of my reasoning upon these problems.

I am aware that Professor Lesley * finds (for himself) an argument for the "expansion theory" of gas pressure in the gradual decline of the gas pressure at Murraysville and Grapeville; but he overlooks some very simple truths. During a great fire in a town supplied with water by elevated reservoirs (artesian pressure), when a dozen fire plugs are open and running under full headway, the pressure in all the street mains is greatly reduced, and yet the height of the column of water (reservoir) remains the same, and the original pressure will return when the fire is over (the water plugs being closed). Also in the distribution of illuminating gas, the pressure rapidly decreases soon after dark, when so many exits for the gas have been opened (gas jets lighted), though the pressure remains the same at the gas-holders, or has even been increased. The underground tankage of gas is an exactly paralled case to that of water or gas above ground, with the exception that freedom of movement must be infinitely greater above than below ground, on account of the capillary nature of the underground conduits; and hence *a priori* we should expect that the opening of several exits for the escape of the subterranean gases would be more marked in decreasing the pressure upon such con-

* Proc. Am. Phil. Soc., vol. xxix, 1891, p. 16.

duits. But if it were possible to close up all of these exits (gas wells) there can be little doubt that the original pressure would finally return. Of course in such a case the water would crowd into the rock and encroach upon space hitherto occupied by gas until it had compressed the remaining gas into a narrower compass and restored its original pressure.

APPLICATION OF THE "ANTICLINAL THEORY."

This question of the cause of gas pressure is of more importance in connection with the geology of oil than might at first thought appear, as will be subsequently shown. It was largely upon this theory of the origin of gas pressure that I concluded that the Mount Morris oil belt would, when traced southwestward, cross the Baltimore and Ohio railway near Mannington, 25 miles in advance of any oil developments at the time the prediction was made. My working hypothesis was that since the gas pressure is due to a column of water, and since this must be practically the same for any limited area where the rock lies at the same depth below sea level, the oil deposit in this particular rock must extend across the country along the strike of the beds, in a pool comparable to the surface of a lake or a chain of small lakes, if the rock reservoir should not be equally porous everywhere along the strike. Hence, if my theory is true, it would only be necessary to follow the strike of any particular coal bed, limestone, or other stratum outcropping where the oil was actually developed in order to trace the course of the oil belt upon the surface, and thus to determine with approximate accuracy, many miles in advance of the drill, the location and width of such possible oil territory. Very fortunately for my purpose, two persistent coals, the Waynesburg and the Washington beds, cropped to the surface at Mount Morris, the first well finished there by Mr. E. M. Hukill, in October, 1886, starting immediately on top of the Waynesburg seam.

My first work was to determine the tide elevation of these coal beds, especially the Waynesburg, with reference to oil, gas and salt water as developed by the Mount Morris borings. For this purpose one of my associates, Professor T. M. Jackson, then professor of civil engineering at the West Virginia university, ran a line of levels from the Monongahela river (using a Baltimore and Ohio railway datum) out to the oil field, and made a complete survey and map of the twenty or more wells that had been drilled at that time (January, 1889) in and about the village of Mount Morris. He also obtained the elevations of the coal beds at every possible point. From the data thus acquired it was learned that wherever the Waynesburg coal has an elevation of 950 feet above tide, gas, and not oil, was found, and that where it had dipped down below 870 feet salt water was a certainty—in the Mount Morris region at least. As the

Washington coal is 155 feet above the Waynesburg bed, the gas and salt-water limits were found to be 1,105 and 1,025 feet above tide respectively, when referred to the Washington bed as a datum line.

With these facts in hand, it was only a question of correct identification, or tracing of coal beds, and a simple matter of leveling, in order to follow the strike of the surface rocks at least, for a hundred miles or more. But the query arose to me, "Suppose the surface rocks do not lie parallel to the oil sand, then where will the oil belt be found?" The interval between these coal beds and the oil sand might either thin away considerably or thicken up an equal amount in passing southward from Mount Morris. Of course, if either of these things should happen, the strike of the oil sand would not run with the strike of the surface rocks, but would gradually veer away from the latter either eastward or westward, depending upon whether the intervening measures should thicken up or thin away. To meet any such possible contingencies, the territory within which it was considered possible for oil to exist was gradually widened southward, and at Mannington extended eastward to where the Waynesburg coal had an elevation of 1,025 feet instead of 950 (the eastern limit of oil at Mount Morris), and carried westward to where it had an elevation of 800 instead of 870 feet (the western limit of oil at the north).

In following the strike line from Mount Morris to Mannington its direction was found to vary greatly. For the first five or six miles between Mount Morris and Dolls run the strike was about S. 30° W.; but toward the head of Dolls run, the line turned rapidly westward, making a great curve or elbow and running westward past the village of Fairview, from which, with many curves and sinuosities, it crossed successively Plum run, Mods run and Buffalo creek at Mannington, on a general course of S. 45° W., but varying from this 10° to 15° either way in certain localities. The strike line carried on southward from Mannington passed into Harrison county through the villages of Pleasantville and Grangeville.

This course which I thus mapped out for the extension of the Mount Morris oil belt was so crooked and passed so much farther westward than the practical oil men had considered possible that my geological line, or hypothetical belt, furnished occasion for many jokes and gibes at my expense among the oil fraternity; and it was with the greatest difficulty and only by liberal gifts of supposed oil territory that I could induce any of them to risk their money on a purely geological theory. Finally, however, a contract to drill a test well in the vicinity of Mannington was entered into in the spring of 1889 with Mr. A. J. Montgomery, of Washington, Pennsylvania, a gentleman who had given considerable thought to geology. As this was to be a crucial test of my theory, the proper location for the test, 20 miles distant from any producing oil well, gave me no little concern, since if the well should prove a failure oil geology would receive a fatal blow, in the eyes of practical oil men, while if successful their confidence in geology would be greatly increased and strengthened.

The problem I had to solve was, whether the interval between the surface rocks and the oil sand would remain the same as at Mount Morris, or whether it would either thicken or thin; since, upon my theory, if I made a location at Mannington where the Waynesburg coal had an elevation of 900 feet above tide, and the interval from it to the oil sand remained the same (1,625 feet) as at Mount Morris, then if the oil rock proved open and porous a fair oil well should be found; while if, on the other hand, this interval should thin away to, say, 1,575 feet, then gas would be found, and if it should thicken up to 1,675 feet, salt water would be obtained, and this especially would be fatal to my theory, for the practical oil men were predicting that Mannington was several miles too far westward, and hence was in salt water territory. In the absence of any evidence bearing upon the subject, and rather in opposition to a general geological fact, viz, that the sedimentary beds thin away rapidly westward from the Alleghanies, I made up my mind to take no chances on salt water in this, the first test well, and in finally determining the location, placed it where the Waynesburg coal had an altitude of 970 feet and the Washington about 1,125 feet. Such a location at Mount Morris would have been in the gas belt by an elevation of 20 to 25 feet to spare.

As the drill progressed it was found that the intervening rocks were thickening instead of thinning when compared with the Mount Morris column, and when the top of the oil sand ("Big Injun") was finally struck, the interval from it to the Waynesburg coal measured exactly 1,725 feet instead of 1,625, as at Mount Morris. Finally, on October 11, 1889, the drill penetrated the oil-bearing zone of this sand, and was immediately followed by a copious showing of oil, the result being that my theory was at once raised from the domain of conjecture to that of demonstrated fact. Thus a great victory was won for geology, since it taught the practical oil men once for all that they could not afford to disregard geological truths in their search for oil deposits.

This thickening of the interval between the Waynesburg coal and the oil sand to the extent of 100 feet, in the distance of 25 miles from Mount Morris to Mannington, proved to have exactly the effect that I anticipated, *i. e.*, it caused the oil belt to veer eastward until (as may be seen by the accompanying map, plate 6) it gradually encroaches upon the territory occupied by the gas belt in the vicinity of Mount Morris; so that the *western* edge of the oil belt at Mannington is found where the Waynesburg coal has an altitude of 950 feet above tide, which is where the *eastern* edge occurs at Mount Morris, and the gas belt begins; and hence, had the first location at Mannington been made without taking into account a possible thickening, the well would have been too far westward, and a dry hole or salt water would have been the certain result. The amount of this eastward shifting of the strike of the oil sand compared with the strike of the surface rocks between Mount Morris and Mannington is something more than half a mile, and is exhibited to the eye on the accompanying map by following the 1,000 feet elevation of the Waynesburg coal between the two points. The black line representing the strike of this bed at that elevation will be seen to lie east of the oil belt at Mount Morris, but at Mannington the oil belt is found with its eastern edge just east of this 1,000 feet strike line.

Since this Mannington test well was drilled, about 200 others have been sunk along the belt, as previously defined by me, between Mount Morris and Mannington; and the correctness of my theoretical work has been demonstrated by the drill in opening up along this belt through Marion and Monongalia counties one of the largest and most valuable oil fields in the country. Fewer dry holes have been found along this belt than on any other oil belt known to me, not more than 5 per cent of the wells drilled within the defined limits proving totally dry.

It is not claimed that this same chain of reasoning can be applied with like successful results to the discovery and development of every great oil field that yet lies hidden below the surface of the Appalachian plateau, but it is believed that a correct understanding and appreciation of the principles involved and used in the discovery of the Mannington oil field cannot fail to prove most useful and helpful to both operator and geologist in limiting the expensive exploration of the drill to regions where the geological structure would indicate favorable locations for oil deposits. Of course no sedimentary bed can extend indefinitely in any direction, or even for considerable distances, without undergoing a change in the character of its constituent elements. The individual particles of which it is composed must vary in size, and the cementing material, or lack of it, must be an ever-changing quantity. For these reasons any oil rock must be quite variable in porosity, and hence its productiveness cannot be a constant amount. Where the oil sand is a mere bed of coarse gravel or pebbles like that in the famous McDonald region of Washington county, Pennsylvania, or in the great Russian oil field, then the production of an oil well seems to be limited only by the size of the bore hole; while, on the contrary, the producing rock may become so close and compact within a few feet from a large producer as to be practically barren of oil. This fact was strikingly illustrated recently at McDonald, Pennsylvania, since at the very time the famous Mevey well number 1 was gushing oil at the rate of 15,000 barrels daily, another well was drilled through the same "Fifth sand," only 300 feet distant, and proved to be practically dry—the character of the producing rock having undergone a great change and become so close-grained within such a short distance that it could not hold oil in paying quantity. If such changes as this can happen in the character of an oil rock reservoir within a few feet, much more would we expect such changes within a few miles; and thus it happens that although there appears to be a continuous deposit of oil in the Mount Morris sand, from the Pennsylvania line southward to Mannington, and for at least six miles beyond, yet the productiveness of the rock is not everywhere the same, because the character of the sand (reservoir) is not constant. This condition of affairs tends to concentrate the richest territory into pools of greater or less extent which are separated from each other by territory that is "spotted" or less productive.

When this tendency to change in the character of the sand or reservoir is carried so far as to render the rock impermeable to gas, oil or water for a considerable distance, then any oil belt must come to an end, and we need not expect it to set in again on the same strike of the rocks (though that is possible), but rather when the same stratum becomes again productive it will be found at a lower or higher level and on a different strike line, so that in this way we may have several parallel belts of oil in the same stratum, and occupying different levels with reference to their tidal elevation. Thus, there are numerous productive belts of the old Third Venango oil sand from Titusville, where it lies several hundred feet *above* tide, down to the southwestern corner of Pennsylvania, where it is 2,000 feet *below* tide. Hence the principles illustrated in this paper have a local as well as a general application—local, to enable the operator to follow the course of the oil belt when discovered; and general, to enable him to limit his search for oil territory to the localities where the geological structure is favorable.

An effort has been made to find oil on the Mount Morris-Mannington belt in Harrison, Doddridge and Gilmer counties southwest of Marion; but the oil rock has changed its character completely along the strike of this belt, becoming slaty and changing to limestone; so that although some oil and gas have been found in this stratum in both Doddridge and Gilmer counties, 50 miles from Mannington, the rock is too close-grained to hold oil in merchantable quantity. Nevertheless, its presence in small quantity at the right geological and tidal elevation at distances along the strike so far away from Mannington as Big Isaac in Doddridge county and Tannersville in Gilmer demonstrates the correctness of the structural theory.

Just where the Mannington belt will end toward the southwest is, as yet, uncertain. Oil has been developed along it to within one mile of the Harrison county line, but in my opinion the belt will end not far from the latter point, since at the farthest well in advance (Blaker number 1) the sand is becoming limy and much split up with slate.

It is quite probable that in passing westward from this non-productive region down the dip of the rocks through Harrison, Gilmer and Doddridge counties the sand may improve in quality, and another belt on a different strike may be found, since there is a dip of about 300 to 400 feet before we come down to the bottom of the geological slope and reach the floor of the Appalachian basin.*

The lower group, or Venango oil sand, has not yet produced oil in any of the half dozen wells drilled through these sands along the Mount Morris-Mannington belt, but some gas has been found in Marion and Harrison counties and quite a large flow in Doddridge county; so that there can hardly be any doubt that when the proper search is made in these sands further down the slope of the rocks than in the few trial borings already made, oil will be developed in large quantity, just as certainly as the drill shall find a good, porous sand reservoir in this series of deposits, since the group of beds making up the Venango series is still present in Monongalia, Marion, Harrison and Doddridge counties, at least, and of about the same thickness and structure as in Washington and Greene counties, Pennsylvania.

The Origin of Petroleum.

The geological structure in the Mount Morris-Mannington field is so plainly connected with the accumulation of the oil deposits that considerable light is thrown upon the much mooted problem as to the genesis of petroleum.

The gas is on one side of a long slope of sand, with salt water on the other and the oil between. Did the petroleum in this Mount Morris sand come up from below and simply stop in the sand as a reservoir because it could not escape to the surface, or did it originate in the sand rock itself? The rock is an ancient sea-beach or shallow water deposit, and where exposed at many localities in the country contains marine shells, fucoids, and frequently land plants in such quantity as to form thin coal seams, which have even been found by the drill in regions where this rock is barren of oil; so that there was evidently no lack of organic matter in the original deposition of the rock. When the drill descends below this stratum a succession of gray and red shales, with other sand rocks, occurs

*Since the reading of this paper a promising oil well has been drilled at Center Point, Doddridge county, several miles west of the Mannington strike line.

in the next 1,000 feet, there being but little bituminous slate in that interval, and probably none for an interval of 3,000 feet more, or until the horizon of the Marcellus slate of the Hamilton series is reached.

Does it appear probable that this petroleum has ascended through nearly a mile of close-grained slates and sandstones, and simply stopped on its upward course at the horizon in which we find it? I think not; but rather that the organic matter deposited with and in the sandstone has been converted into petroleum and gas within the rock itself, and that the tilting of the beds has permitted the small quantities of water, oil and gas in all the porous portions of the rock to rearrange themselves in the order of their several specific gravities under the artesian pressure to which the rock is subjected, so that merchantable quantities of each have been accumulated. This seems to be the more probable origin of the Mount Morris-Mannington oil pool, at least, though of course the particles of oil, gas and water would rearrange themselves in the manner found however they might have come into their present reservoirs.

APPENDIX.

THE "ANTICLINAL THEORY" OF NATURAL GAS.*

BY I. C. WHITE, OF THE U. S. GEOLOGICAL SURVEY.

At the request of the editor of this paper the writer has consented to arrange an article for publication on the above subject. As many of the readers will perceive, it consists principally of what has already been published by me in other journals, but here brought together and condensed into one paper for the convenience of those interested in the subject.

The "anticlinal theory" of gas is not entirely new, since both Dr. Newberry and Dr. Stevenson long ago recognized *disturbance in the rocks* as a factor in the occurrence of oil (and consequently of gas).

Also, Mr. F. W. Minshall, an oil operator of many years' experience, had, it seems (from a recent letter in *The Petroleum Age*), several years since, recognized the connection between anticlinal structures and large deposits of natural gas, and it is quite probable that the same conclusion has been formulated in the minds of many other oil operators from the results of their practical experience in drilling; but so far as the writer knows, Mr. William A. Earseman was the first person who proposed to test the theory practically by locating trial borings for gas on the crests of anticlinal folds.

The subject was first brought prominently to the attention of geologists and others interested in natural gas by a short paper from the writer published in *Science* of June 26, 1885, and as the statements therein contained embrace the "anticlinal theory" as held by its friends and promulgators, it is here republished in full, in order that its claims may not be misrepresented. The paper in question read as follows:

"The recent introduction of natural gas into general use as a source of heat for industrial and domestic purposes has raised it from the rank of a mere curiosity to one of the earth's most valuable treasures.

"To the reader unacquainted with the great change natural gas has effected in all industries where it can be obtained, the following quotation from an article in *Macmillan's Magazine* for January, written by Mr. Andrew Carnegie, the chief iron master of Pittsburg, will be a revelation: 'In the manufacture of glass, of which there is an immense quantity made in Pittsburg, I am informed that gas is worth much more than the cost of coal and its handling, because it improves the quality of the product. One firm in Pittsburg is already making plate glass of the largest sizes, equal to the best imported French glass, and is enabled to do so by this fuel. In the manufacture of iron, and especially in that of steel, the quality is also improved by the pure new fuel. In our steel rail mills we have not used a pound of coal for more than a year, nor in our iron mills for nearly the same period. The change is a startling one. Where we formerly had 90 firemen at work in one boiler-house, and were using 400 tons of coal per day, a visitor now

* Reprinted from the "Natural Gas Supplement" to the *American Manufacturer* for April, 1886, pp. 11-13.

walks along the long row of boilers and sees but one man in attendance. The house being whitewashed, not a sign of the dirty fuel of former days is to be seen; nor do the stacks emit smoke. In the Union iron mills our puddlers have whitewashed the coal-bunkers belonging to their furnaces. Most of the principal iron and glass establishments in the city are today either using this gas as fuel or making preparations to do so. The cost of coal is not only saved, but the great cost of firing and handling it; while the repairs to boilers and grate-bars are much less.'

"This new fuel, which bids fair to replace coal almost entirely in many of our chief industrial centers, has not received that attention from the geologist which its importance demands. So far as the writer is aware, nothing has been published on the subject which would prove of any value to those engaged in prospecting for natural gas, and it is the existence of this blank in geological literature that has suggested the present article.

"Practically all the large gas wells struck before 1882 were accidentally discovered in boring for oil; but when the great value of natural gas as fuel became generally recognized, an eager search began for it at Pittsburg, Wheeling and many other manufacturing centers.

"The first explorers assumed that gas could be obtained at one point as well as at another, provided the earth be penetrated to a depth sufficiently great; and it has required the expenditure of several hundred thousand dollars in useless drilling to convince capitalists of this fallacy, which even yet obtains general credence among those not interested in successful gas companies.

"The writer's study of this subject began in June, 1883, when he was employed by Pittsburg parties to make a general investigation of the natural gas question with the special object of determining whether or not it was possible to predict the presence or absence of gas from geological structure. In the prosecution of this work I was aided by a suggestion from Mr. William A. Earseman, of Allegheny, Pennsylvania, an oil operator of many years' experience, who had noticed that the principal gas wells then known in western Pennsylvania were situated close to where anticlinal axes were drawn on the geological maps. From this he inferred there must be some connection between the gas wells and the anticlines. After visiting all the great gas wells that had been struck in western Pennsylvania and West Virginia, and carefully examining the geological surroundings of each, I found that every one of them was situated either directly on or near the crown of an anticlinal axis, while wells that had been bored in the synclines on either side furnished little or no gas, but in many cases large quantities of salt water. Further observation showed that the gas wells were confined to a narrow belt, only one-fourth to one mile wide, along the crests of the anticlinal folds. These facts seemed to connect gas territory unmistakably with the disturbance in the rocks caused by their upheaval into arches, but the crucial test was yet to be made in the actual location of good gas territory on this theory. During the last two years I have submitted it to all manner of tests, both in locating and condemning gas territory, and the general result has been to confirm the anticlinal theory beyond a reasonable doubt.

"But while we can state with confidence that all *great gas wells* are found on the anticlinal axes, the converse of this is not true, viz, that *great gas wells* may be found on *all anticlinals*. In a theory of this kind, the *limitations* become quite as important as or even more so than the theory itself; and hence I have given considerable thought to this side of the question, having formulated them into three or four general rules (which include practically all the limitations known to me, up to the present time, that should be placed on the statement that large gas wells may be obtained on anticlinal folds), viz:

(*a*) "The arch in the rocks must be one of considerable magnitude.

(*b*) "A coarse or porous sandstone of considerable thickness, or, if a fine-grained rock, one that would have extensive fissures, and thus in either case rendered capable of acting as a reservoir for the gas, must underlie the surface at a depth of several hundred feet (500 to 2,500).

(*c*) "Probably very few or none of the grand arches along mountain ranges will be found holding gas in large quantity, since in such cases the disturbance of the stratification has been so profound that all the natural gas generated in the past would long ago have escaped into the air through fissures that traverse all the beds.

(*d*) "Another limitation might possibly be added, which would confine the areas where great gas flows may be obtained to those underlain by a considerable thickness of bituminous shale.

(*e*) "Very fair gas wells may also be obtained for a considerable distance down the slopes from the crests of the anticlinals, provided the dip be sufficiently rapid, and especially if it be irregular or interrupted with slight crumples. And even in regions where there are no well marked anticlinals, if the dip be somewhat rapid and irregular, rather large gas wells may occasionally be found, if all other conditions are favorable.

"The reason why natural gas should collect under the arches of the rocks is sufficiently plain, from a consideration of its volatile nature. Then, too, the extensive fissuring of the rock, which appears necessary to form a capacious reservoir for a large gas well, would take place most readily along the anticlinals where the tension in bending would be greatest.

"The geological horizon that furnishes the best gas reservoir in western Pennsylvania seems to be identical with the first Venango oil sand, and hence is one of the Catskill conglomerates. This is the gas rock at Murraysville, Tarentum, Washington, Wellsburg, and many other points. Some large gas wells have been obtained in the Subcarboniferous sandstone (Pocono), however, and others down in the third Venango oil sand (Chemung).

"In Ohio, gas flows of considerable size have been obtained deep down in the Cincinnati limestone, while in West Virginia they have been found in the Pottsville conglomerate: hence natural gas, like oil, has a wide range through the geological column, though it is a significant fact that it is most abundant above the black slates of the Devonian."

The conclusions announced in the foregoing article were criticised by Mr. Charles A. Ashburner, geologist in charge of the geological survey of Pennsylvania, who claimed, in effect, that the relation between gas wells and anticlinals was one of coincidence merely, or of the same nature as Angell's "belt theory" of oil, and also that large gas wells could be found in synclines.

To this criticism the writer published the following reply in *Science*, of July 17, 1885:

"In reply to Mr. Ashburner's criticism of the views advanced in my article on natural gas, I would say that the necessary brevity of the paper in question prevented the mention of many facts that might have rendered the conclusions clearer and less open to challenge. One of these is that my communication had especial reference to the natural gas regions proper, *i. e.*, where the gas is unconnected with oil fields. Most geologists know that natural gas in large quantities exists with and contiguous to every oil pool, apparently as a by-product in the generation of the oil, and of course the rocks are filled with it wherever it can find a reservoir. To gas wells from such sources Mr. Ashburner's criticism may sometimes be found applicable; but, even with these, by far the larger ones will be found on the arches of the rocks.

"The cases that Mr. Ashburner mentions, where large gas wells have been found at the centers of synclines, do not necessarily contradict my conclusions; for no one knows better than he that a subordinate crumple or anticlinal roll often runs along the central line of a syncline.

"My excuse for writing the article on natural gas was that I might be of some service in preventing the waste of capital that has been going on within a radius of fifty miles from Pittsburg by an indiscriminate search for natural gas; and it is a sufficient answer to Mr. Ashburner's criticism to point him to the brilliant lights along the crests of the Waynesburg, Pinhook, Washington, Bull creek, Bradys bend, Hickory, Wellsburg, Raccoon, and other anticlinals, and also to the darkness that envelops the intervening synclines, in which hundreds of thousands of dollars have been invested without developing a single profitable gas well. The same result has been proven in other portions of the country. The Great Kanawha valley above Charleston has been honeycombed with borings for salt, and the only gas wells developed were found within a belt a few rods wide, which coincides with the crest of the Browntown anticlinal, where immense flows were struck. In this connection I should state that Colonel Allen, of Charleston, says he can trace the Browntown anticlinal by the escaping gas across streams, and even mountains, from the Kanawha river to the Big Sandy, where, on its crest, near Warfield, two of the largest gas wells ever known have recently been struck. At Burning springs, on the Little Kanawha, the only large gas wells were found on the very crest of the great uplift in that region. The gas belt of western Ohio, through Findlay and other towns, follows closely the line of the Cincinnati arch, and the same story is repeated in other localities too numerous to mention.

"Mr. Ashburner can, if he chooses, interpret these facts as mere coincidences, and explain them to himself as having no more bearing on the question of finding gas than "Angell's belt theory" of oil; but the practical gas operator can no longer be deluded by such logic into risking his money in water-holes (synclines) where so many thousands have been hopelessly squandered.

"With regard to the anticlinal theory not being 'a practical basis for successful operations,' I deem it a sufficient reply to state that all the successful gas companies of western Pennsylvania and West Virginia are getting their gas from the crests of anticlinal axes, while those that have confined their operations to synclines have met with uniform financial disaster.

"The statement was distinctly made in my original communication that gas would not be found on all anticlinals, nor at all localities along one that actually produces gas, since other factors have to be considered, as there stated; but, with the facts before us, it would certainly prove a great saving of capital in the search for gas if operations were confined to the crests of the anticlinals, and I fail to perceive how Mr. Ashburner's fears for the 'misleading' character of my article can be realized."

Mr. Ashburner replied to this in *Science* of September 4, 1885, and has written further on the subject in a paper read before the American Institute of Mining

Engineers, Halifax meeting, 1885, and also in *The Petroleum Age* for January, 1886. As a general reply to these strictures and also to illustrate the theory more fully, the writer prepared a paper for *The Petroleum Age* which was published in the March number of that journal, along with a map of western Pennsylvania, on which were located the principal anticlinal lines, and also the large gas wells. Since the article in question contains several points of interest not hitherto given to the public, the principal portion of it is here republished, without the map, which can be procured from *The Petroleum Age* by any reader who wishes it for reference:

"Where the anticlinal lines are drawn full on that map they represent actual observations of myself or others, but the dotted lines are projections of arches observed only at a few points; for instance, Mr. Ashburner states that the Sheffield gas wells are on the crest of an anticline, and when the Martinsburg axis of Mr. Chance is projected approximately parallel to the others it passes through the Sheffield region; hence the two are assumed to be identical, and the same principle has been followed in making the other projections.

"There are probably other flexures in the rocks which traverse the district in question that, in the rapid survey made of some of the counties, were not detected by the assistant geologists of the Pennsylvania survey. The writer pleads guilty to some mistakes of this nature, as well as of getting one anticlinal confused with another, in the case of the Fredericktown uplift. This mistake, which was corrected by Mr. H. Martyn Chance, in report V, may possibly have been duplicated by others of the assistants before they became expert at detecting minute changes in dip or stratification.

"An inspection of the accompanying map will reveal the fact that the main northeast and southwest anticlinals are cut by another set at nearly right angles, which have been termed cross-cut anticlinals. To Mr. Ashburner belongs the credit of first calling the attention of geologists to this feature in the rock structure of Pennsylvania, and the great Kinzua-Emporium cross-cut wave which he first traced through Cameron, Elk and McKean counties is shown on the present map.

"The surveys of the western counties of Pennsylvania were practically finished before the publication of Mr. Ashburner's observations in the northern portion of the state, and hence although similar phenomena were observed they were not described in similar terms or referred to similar causes. Thus, Stevenson (as well as Rogers long ago) recognized a great bulge in the Chestnut ridge uplift, near Uniontown, by which the Hamilton rocks are elevated to the summit of the mountain, but the arch dying down both north and south, the Catskill rocks fail to reach the surface where the axis crosses the gorge of Cheat river in the one direction, and the Chemung beds are completely buried at the Conemaugh gap in the other.

"During the last two years the writer has given considerable thought to these cross-cut axes, and the results show that a cross-cut anticlinal (presumably identical with the one crossing Chestnut ridge near Uniontown) goes through the famous Cannonsburg and Hickory gas regions in Washington county, while another parallel to it, and a few miles west, goes through the village of Pinhook, or Lone Pine, and also cuts the McGuigan gas field.

"Another of marked extent has recently been traced by the writer through the Murraysville and Grapeville region of Westmoreland county, the greatest gas field in the world, so far as present developments show. Groups of wells also appear to cluster along the grand arch that Mr. Ashburner has traced through northern Pennsylvania.

"Having observed the importance of these cross-cut arches in the location of gas territory, I wrote Mr. Ashburner, suggesting that there might be some disturbance of the rocks in the region of Kane, where he claimed large gas wells were found in an undisturbed syncline.

"The recent discovery of oil in the Kane region has led to the drilling of many wells, and in the Oil City *Derrick* of a recent date the statement is made on the authority of Mr. McKinney, of the Union oil company, that a rapid northward dip had been found, *i. e.*, a subordinate cross-cut anticline parallel to the main one north of Kane passes through the Roy and Archer gas region. Whether this shall turn out true or otherwise, there is certainly no inherent improbability against finding such subordinate waves.

"Very unexpected and surprising was the testimony on this head which came to me recently from Mr. L. R. Curtiss, of Mendota, Illinois, who, unknown to myself, made a careful study of the geological conditions under which natural gas occurs in that state, and reached the same conclusions quite independently of my own views, as will be seen from the following paragraphs, quoted by permission from his letter to me on the subject:

"'The principal anticlinal axis of Illinois puts out in Ogle county, in the northern part of the state, and extends in a direction S. 20° E. through La Salle and Champaign, and thence to Coles and Clark counties, in the southeastern part of the state. Along this axis natural gas can be traced in springs and well borings for a distance of 160 miles. *It is, however, more prevalent on the crowns of the cross-axes.* This is notably the case at Mendota, where the cross-axis intersects the main anticline at an angle of 85° (running S. 65° W.), and on the summit of this fold the gas belt extends southwestward into Bureau county for over twenty-five miles. The other cross-axes located further to the south intersect two or three low anticlinals toward the Mississippi, and trend in the direction of the gas fields in McLean, De Witt, Macon, and Montgomery counties.'

"This same story is repeated in Ohio, according to the testimony of the eminent state geologist, Professor Orton (see his letter in Ohio *State Journal* of recent date).

"Now what is the effect of these cross-cut axes on geological structure? Evidently one effect would be to cause the arches and corresponding troughs themselves to rise or sink, as we approach or recede from the cross-cut as the case may be; for example, the general rule is that the rocks of western Pennsylvania dip down to the southwest along the line of the anticlinals, as well as away from them (N. W. and S. E.), but in the region of Cannonsburg this rule is reversed and the rocks *rise* rapidly (seventy-five feet per mile) to the southwest along both anticlinals and synclinals until the crest of the Hickory-Houstonville cross-cut arch is passed, when a rapid *dip* begins in the same direction (southwestward), thus forming at the points of intersection a kind of "hog-back" structure (as Mr. Earseman terms it) from which the rocks dip away in every direction.

"Hence these cross-cut arches result in carrying the anticlinal structure and a line of disturbance in the rocks directly across the trend of a syncline, and a failure to grasp this fact is the principal reason why Mr. Ashburner insists upon his readers believing that a great gas well may be obtained in a syncline; for it is quite certain that no large gas well has ever yet been found in the trend of a syncline, except where the trough itself has been elevated by a long rise from the southwest, which is, of course, brought about by the cross-cut folds.

"These are the geological surroundings of all those wells which Mr. Ashburner cites from northern Pennsylvania and southern New York as occurring in synclines. It is not necessary to show a reversed or northeast dip in order to demonstrate the existence of one of those cross-cut waves, since their crests are (like some of the main northeast and southwest anticlinals) often marked by a simple flattening of the rate of dip along the latter. Professor Orton would call such a structure (where there is no reversal of dip, but only a change in rate) a *suppressed anticlinal*, a very good name, for such it really is.

"It follows, of course, that as a synclinal structure may be converted into an anticlinal one by the presence of the cross-cut wave, so the reverse may and frequently does happen, of which we have a notable instance in the region immediately adjoining Pittsburg. Here the anticlinals all sink down toward the southwest until we reach the bottom of a cross-cut trough, where they begin to rise again toward Cannonsburg, the result of which is to flood all the porous rocks under Pittsburg with salt water. The numerous wells drilled at Pittsburg show a good reservoir (Mr. Ashburner's prime factor for gas wells); but geological structure dominates here as everywhere else, and fills the reservoir with water, so that the little gas obtainable is practically useless, though when structure has elevated this reservoir out of the water at Tarentum on the north and Cannonsburg on the south, gas is obtained in abundance.

"Another cross-cut anticlinal passes along the Conemaugh river, intersecting Leechburg and Butler, its path being marked by a line of gas wells across synclinals as well as anticlinals.

"Having now glanced at some of the general structural features under which large gas wells are found, we shall consider a few of the individual arches and troughs in order to illustrate some of the general principles to which reference has been made.

"*Laurel Hill and Chestnut Ridge Anticlinals.*—The arches made by these great axes would, in my opinion, come under the ban of exception (*c*), and hence the rocks would probably be fissured too much to retain large quantities of gas. This is only an inference from theory, however, since so far as I am aware only one or two wells have been bored near the crown of either arch. One of these was bored for oil in Monongalia county, West Virginia, where the Chestnut ridge axis crosses Decker's creek, six miles southeast of Morgantown. This well began at the base of the no. XI limestone and descended about 400 feet, and hence did not penetrate the great Murraysville gas horizon (first Venango oil sand). Whether or not these large arches may furnish gas when they have flattened out to much lower waves in northern Indiana and Cambria counties is a question that only the drill can settle, though the fact that some gas was obtained at Cherry Tree, near the Nolo anticlinal (between Laurel hill and Chestnut ridge), would seem to render the hope not entirely groundless. In fact it is within the range of possibility (though not probable) that if a hole were sunk to a great depth on these arches, where they exhibit even a large development, gas might be found. The drill has this question to settle yet, since the two deep wells drilled in the synclines at Johnstown and Wellersburg could not be expected to find gas. Those drilled in the Ligonier valley were also in a syncline, and hence obtained only small quantities of gas.

"Coming still further westward we find that several wells have been bored along the western slope of Chestnut Ridge, about half way down the dip from the crown of the arch. One of these on Deckers creek and two on Cheat river, West Virginia, found a considerable quantity of gas in no. XII (the first great gas horizon), but the rock, as might have been expected, was filled also with water, which rendered the gas useless. The wells bored under nearly the same conditions as to locations in Westmoreland county found very little gas.

"The next arch westward from Chestnut ridge is the Indiana axis of Platt. This is a very sharp and well defined wave in Westmoreland county, the vertical distance from the crest to the bottom of the troughs on either side being in some places not less than 800 feet or even more; hence, unless its proximity to the great arch of Chestnut ridge should affect it, we would on the 'anticlinal theory' naturally expect it to furnish good gas wells, provided the proper kind of reservoir exists under the surface. Messrs. Guffey and Mellon have recently finished a well on this arch near Latrobe, which yields from five to six hundred thousand feet of gas daily. Some drilling was once done in the vicinity of Blairsville, where the arch crosses the Conemaugh river, but no large flow of gas was obtained, probably because the well was situated too far from the crest of the arch.

"Going still further northeastward we find the well which supplies the town of Punxsutawney with gas is situated close to this fold.

"The next arch is the great Saltsburg axis of Stevenson, the descent on each side of which is quite as great as that of the Indiana arch. This is far enough away from the Chestnut ridge disturbance to remain unaffected by the latter, and hence ought to furnish a fair test of the 'anticlinal theory.' The writer recently located a well on this arch for J. M. Guffey & Co., just north from the town of Grapeville, and when the Murraysville sand was reached a few weeks ago an immense flow of dry gas was struck.*

"Some gentlemen from Greensburg, however, who, like Mr. Ashburner, seemed to think gas could be obtained in a syncline, drilled a well one mile east from the crest of the arch, at a locality where the dip had carried the rocks down 250 feet below the crest of the Saltsburg wave. The result was that although a splendid reservoir of great thickness was found, it contained an immense supply of water, and consequently what little gas was obtained was worthless. These wells, the one furnishing a large *gas* flow and the other a large *water* flow, are only two and one-half miles apart, the former on the crown of the arch, the latter nearly a mile east from the same. No fairer test than this could be asked for the merits of the 'anticlinal theory.'

"The next arch westward is the *Waynesburg axis*, and the only gas wells obtained along the Monongahela river, among the many that have been bored, are found on its crest at Bellevernon, though the fold being low and flat, no large wells have been struck.

"The great Murraysville arch was regarded by Professor Stevenson as identical with the Waynesburg fold, the latter having been shifted eastward; but, however, this may be, there is no doubt about the one dying away to the north and the other to the south, and hence I have termed the western fold simply the Murraysville axis. This, like many other well known arches in Pennsylvania, is a double fold, with the crests about one-half mile apart, though the depression between them is very slight. As every one knows, the forty or more great gassers in that region are clustered along the Murraysville anticlinal, water being obtained in the synclinal at Irwin on the east and at Walls on the west. 'But,' says the opponent of the 'anticlinal theory,' 'you get water with the gas even along the Murraysville

*"Since this was written two other wells have been drilled to the Murraysville sand, on the crown of the Saltsburg arch, near Grapeville, and competent judges, who have seen all the great gas wells in the country, pronounce them much the largest that have ever yet been struck; so that my prediction of three years ago, that the Grapeville region would furnish larger wells than the Murraysville, has been literally fulfilled. This conclusion was based on *geological structure* alone, since the Grapeville, or Saltsburg arch, is a much grander one than the Murraysville fold. Can Mr. Ashburner explain this away as a case of coincidence of the Angell "belt theory" kind?

arch when you come south of the Pennsylvania railroad; hence of what account is the theory, anyhow?' 'My critical friend,' we answer, 'you have not observed wisely, else you would have seen that the Murraysville arch dies down and flattens out very rapidly into the great cross-cut syncline trough which embraces the city of Pittsburg, and a broad belt on either side, and the 'anticlinal theory' of gas teaches that it is quite as unwise to expect large gas wells on an arch so situated structurally as in a genuine syncline; for whenever the dip along the axial line begins to equal or surpass the total height of the wave, water may be confidently expected.' Hence, although some very large flows of gas have been struck near where the Murraysville arch crosses the Youghiogheny river, yet the quantity of water in the rock was so great that the gas was soon drowned out. The same principle accounts for the water in the Venice well of Washington county, which is located near the structural line of the Bradys bend axis, and so of others that have been pointed to as contradicting the 'anticlinal theory.' And thus we might go over the entire list of anticlinals; but as the story would be practically the same everywhere, it is useless to tire the reader's patience with details. It has been shown that the great gas wells cluster along the anticlinals, and where any marked exception to this rule occurs we find a cross-cut arch is the disturbing cause, and hence the seeming conflict is the strongest confirmation of the real essence of the 'anticlinal theory,' which, condensed and simplified into the fewest words, means that *structure* is the main factor in a search for great gas wells; that *disturbance* in the rocks by which they have been elevated above the same beds in contiguous regions, either on the crest of an anticlinal arch or along the axial lines of the synclines themselves (where cut by the cross-arches) is an essential element in finding large and lasting wells, free from water, and therefore entitled to be called 'great.'

"It is true that a considerable quantity of gas may be so shut in by close rock (through which it cannot pass) as to be imprisoned even in a syncline, and when first struck may deliver a large quantity of gas, and the same may be true where the rocks are nearly horizontal, especially in regions contiguous to oil territory; but such wells soon blow themselves out and cease to deliver gas, like the famous 'Mullen Snorter' and 'Kane Geyser,' which figure so largely in Mr. Ashburner's criticism of the 'anticlinal theory.'

"Reference has also been made to the gas wells at Erie and Fredonia as evidence against the 'anticlinal theory,' since it is claimed there are no anticlinal waves near these localities. To any one who deems these wells evidences against what I have claimed for the 'anticlinal theory,' I must request him to read more carefully the quotations from my original paper found in this article, where he will not find the statement that *all* gas wells occur on anticlinals, but instead, all *great* gas wells are found close to anticlinal arches. Now what is a 'great well?' It is probable that no gas well yet struck ever delivered more than thirty to thirty-five million cubic feet of gas daily. Some have been measured in the Murraysville field that, if we can believe the figures, have yielded thirty-three million feet daily. This is one extreme; but certainly by no stretch of language could the term 'great' be applied to wells like those of Erie, Fredonia and elsewhere along lake Erie which, according to Professor Orton's measurements, yield only from twenty to sixty thousand feet daily.

"Moreover, so far as Erie is concerned, a recent and careful study of the stratification there has revealed to the writer the presence of low waves in the same, approximately parallel to the lake, which were undetected in the necessarily hasty examination made several years ago for the Pennsylvania geological survey.

"As every one knows, it is scarcely possible to penetrate the earth to a considerable depth anywhere within the Paleozoic area (except the rocks are highly contorted) without getting some natural gas, but the *large* supplies are confined to restricted areas, and it was to prevent the waste of capital in an indiscriminate search for these great stores of valuable fuel that prompted my original article on the subject. The drill will, of course, finally settle the question as to whether or not my conclusions were valid. Something, however, has already been accomplished in this line.

"A map of Ohio would reveal the same condition of affairs, for there are only two or three prominent anticlinals in the state, and after the expenditure of a vast amount of money in drilling, the only large gas wells have been found along these lines of *disturbance*. Kentucky, Illinois and West Virginia tell the same story; so that there would seem to be no good reason for any one longer to doubt that *structure* is the great factor in securing large and lasting gas wells.

"If, however, some skeptical capitalist shall ever find large gas wells, free from water, in a genuine syncline, like that at Greensburg, Pennsylvania, or at the bottom of the trough near Irwin, then I shall frankly confess that my judgment has been imposed upon, and that *geological structure* can give no clue to this hidden treasure.

"The reasons why the gas should be stored most abundantly along the arches are so patent that it is unnecessary to state them; the insoluble problem would be how to imprison large quantities of gas in a syncline, except what little might exist in water under high pressure.

"If our main proposition be true, viz, that the principal supplies of natural gas have been stored along the *arches* of the rocks, then the question of *location* must have a very important bearing upon the life of any particular gas field; for whatever may have been the source or origin of the gas, whether as a by-product in the genesis of oil (as much of it certainly is), or from the action of heated saline water on carbonaceous material, thus originating the Murraysville or odorless gas without any oil, as some claim, or in what way soever it is produced, the wells along the arches would have a much longer lease of life.

"Mr. Carll has recently sounded a note of warning through the columns of *The Petroleum Age*, to which those who think the supply inexhaustible would do well to take heed; for certain it is that many wells once large have long since ceased to flow. It is true that many of these have been choked up with salt because the water was not cased off, and the casing having been taken out, a column of water many hundred feet high has imprisoned others, but there is reason for believing that still others have failed because the source of supply was exhausted. On the 'anticlinal theory,' it would be expected that all wells not situated near prominent arches, nor at the upturned ends of vanishing synclines, could not have a long life, since the contents of the reservoir upon which they can draw must necessarily be of limited extent. But not so with those situated along the prominent arches, like that at Cannonsburg, Murraysville and Grapeville; for here the quantity in any one sand will be vastly greater than where the rocks are undisturbed, and the disturbance itself will have fractured the rocks and thus given access to many other reservoirs below the one from which the well draws immediately.

"The first Murraysville well has been delivering from fifteen to twenty million feet of gas daily for nearly ten years, and yet, with many other wells in close proximity, its volume has not yet been appreciably diminished. Hence there is good reason for believing that the gas wells situated on the prominent arches may have a much longer life than others not so fortunately placed, and that the immense amount of capital invested in pipe lines to them will receive an adequate return before the gas shall have been exhausted. Nothing but time can determine the life of gas territory situated upon a well developed arch, like the Murraysville or Saltsburg anticlines.

"In Washington county, Pennsylvania, there are three principal geological horizons at which large supplies of gas are found, and, taking the Pittsburg coal as a datum line, these horizons come in as follows, neglecting fractions:

	Feet.
First horizon, below Pittsburg coal	900
Second " " " "	1,800
Third " " " "	2,000

"The *first* horizon furnishes a gas very much like the Murraysville gas, and the pressure seldom rises above 300 pounds to the square inch. It is contained in the no. XII conglomerate, since the rock lies about 200 feet above the Subcarboniferous limestone.

"The *second* horizon is identical with the first Venango oil sand, and seems to be the gas horizon *par excellence* of southwestern Pennsylvania, since it is also the great producing rock in Beaver, Alleghany, Butler and Westmoreland counties. It is nearly always overlain by a dark, close slate, which has evidently been a factor in enabling the rock to retain the gas. The product of this rock is strongly scented with petroleum in Washington county, but at Murraysville and Grapeville, in Westmoreland, it is nearly odorless, though it is oil-scented again near Latrobe.

"This same rock is the gas reservoir at Wellsburg, West Virginia, and has there been identified by Professor Orton as the Macksburg oil sand, which he in turn identifies with the Berea grit.

"The *third* great gas horizon of Washington county is in the 'stray,' or uppermost member of the third Venango oil sand. The famous McGuigan well is in this sand, as also the Donaldson, Willison, McClean, and others in Washington county.

"The total pressure to which the gas from this rock will rise, when shut in, has never been determined, so far as I am aware, but it would probably exceed that from the first Venango, or Murraysville sand, which seldom rises above 650 pounds to the square inch.

"The explanation of gas pressure in any particular rock seems as yet quite obscure, but there is evidently an increase of pressure with increase of depth, though the law of increase (if there be any law) is not uniform. For instance, the wells at Erie which go down 600 to 700 feet, show a maximum of only 40 to 50 pounds. Mr. Westinghouse, of the Philadelphia company, Pittsburg, suggests that the gas pressure in any case may be due to the water, or hydrostatic pressure on the rock, and this is possibly true, since it would account for the greater pressure as the sand gets deeper below the surface."

Since the above statements with reference to the Washington county gas horizons were written the drill has developed two others, viz, one in the "Big sand," or Manifold farm oil rock, which begins directly under the Mountain or no. XI limestone, and is 250 feet thick. This rock is the upper member of the Pocono sandstone, and is called in Ohio the "salt sand." The horizon in it which furnishes gas is about 1,159 feet below the Pittsburg coal.

The other gas horizon is the so-called "50-foot rock," which has proved so prolific in oil at the Smith no. 1. The top of this sand comes about 1,850 feet below the Pittsburg coal, and it is very probably identical with the second Venango oil sand.

THE CRITICISMS OF THE "ANTICLINAL THEORY" OF NATURAL GAS.*

READ AT THE BUFFALO MEETING OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE, AUGUST, 1886, BY I. C. WHITE.

Through inexcusable carelessness (for I cannot be so uncharitable as to charge intentional misrepresentation), the critics of the "anticlinal theory" of natural gas have invariably misapprehended its claims, and criticised something other than this theory as held and promulgated by the writer.

My critics have almost invariably written about the theory as though it had been claimed that large gas wells could be found everywhere on every anticlinal roll, and in no other situation whatever. Messrs. Ashburner, Chance and Carll, of the Pennsylvania survey, have all set up for themselves this "man of straw," and of course easily demolished him, since no one with whom I have any acquaintance has ever held or published any such theory of natural gas occurrence as they combat. The eminent director of the Pennsylvania geological survey, in his presidential address at Ann Arbor last year, found occasion to refer to the "exploded anticlinal theory of natural gas" as a splendid piece of "dead work," accomplished presumably by the critics already mentioned. It is true that this "dead work" has effectually buried the anticlinal theory as put forth by these critics, for neither the writer nor any one else ever held such a theory; but substantially all that I have ever claimed for it has now been so thoroughly established by the "live work" of the drill, that no geologist, well informed on the subject, will be so rash as to deny the fact.

The gentlemen who have so freely criticised the "anticlinal theory" seem to have stopped reading my first paper on the subject, in *Science* of June 26, 1885, when they came to the *limitations* placed on the theory. On no other hypothesis can I understand the grounds of their opposition. Those who have interest enough in the matter to desire to read my papers on the subject will find all of them in the "Natural Gas supplement" of the *American Manufacturer;* and after having done so, they will find that the essence of it all is, that the great supplies of natural gas have accumulated in the rock reservoirs, in regions of disturbance by which the reservoirs in question have been elevated above contiguous areas of the same beds, and in the lower levels of which oil and water may be expected; or, in other words, gas has accumulated where anticlinals or monoclinals of considerable (but not too great) extent have raised the rocks into arches and other forms of elevation; and hence, as Professor Orton says, *structure* is the main element in the occurrence of gas and oil in large quantity.

The theory teaches that it is useless to bore for large gas supplies in a region where there are no considerable or irregular dips, and hence its negative value is of great importance, since in my own experience but a single failure has been made in condemning such regions; and if any further proof was needed, the larger portion of the state of Ohio bears unmistakable testimony to the negative value of the "anticlinal theory."

But probably the strongest testimony in favor of this theory is the almost universal approval of the practical operators. Many of these, I find, have been guiding their own operations on the same principle for many years, and I very much doubt whether a single operator in Pennsylvania could be induced to drill for gas in a well marked syncline.

*Read by title only at the meeting of the A. A. A. S. in Buffalo, August, 1886; subsequently published in *The Petroleum Age* for November, 1886 (vol. v, pp. 1464, 1465), from which it is reprinted.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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FOSSIL PLANTS FROM THE WICHITA OR PERMIAN BEDS OF TEXAS.

BY I. C. WHITE.

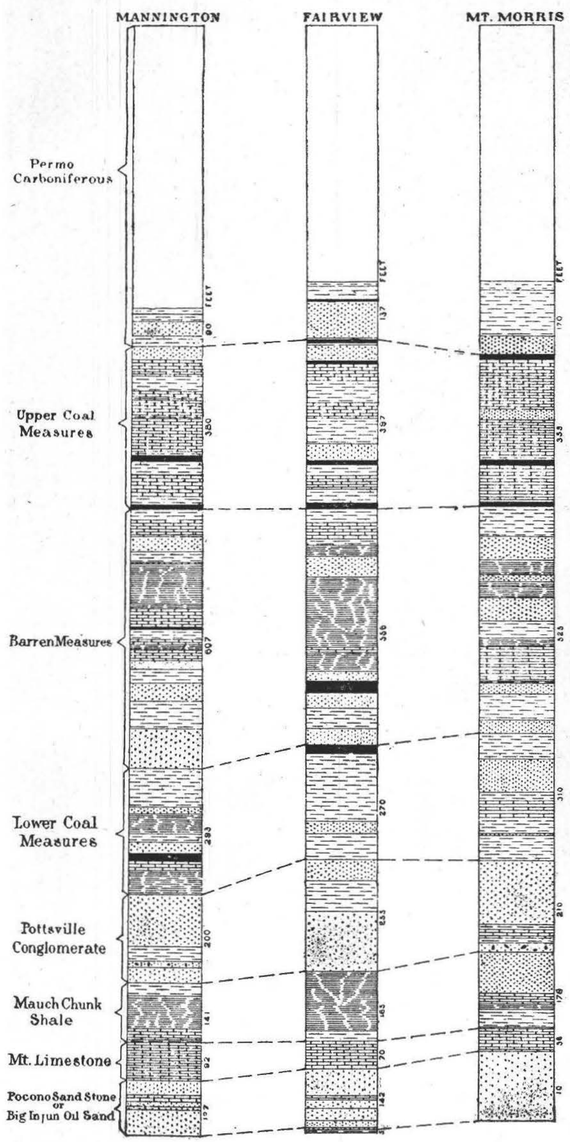
In the spring of the present year, Mr. E. T. Dumble, state geologist of Texas, sent me for examination a small collection of fossil plants from the Wichita beds of that state.

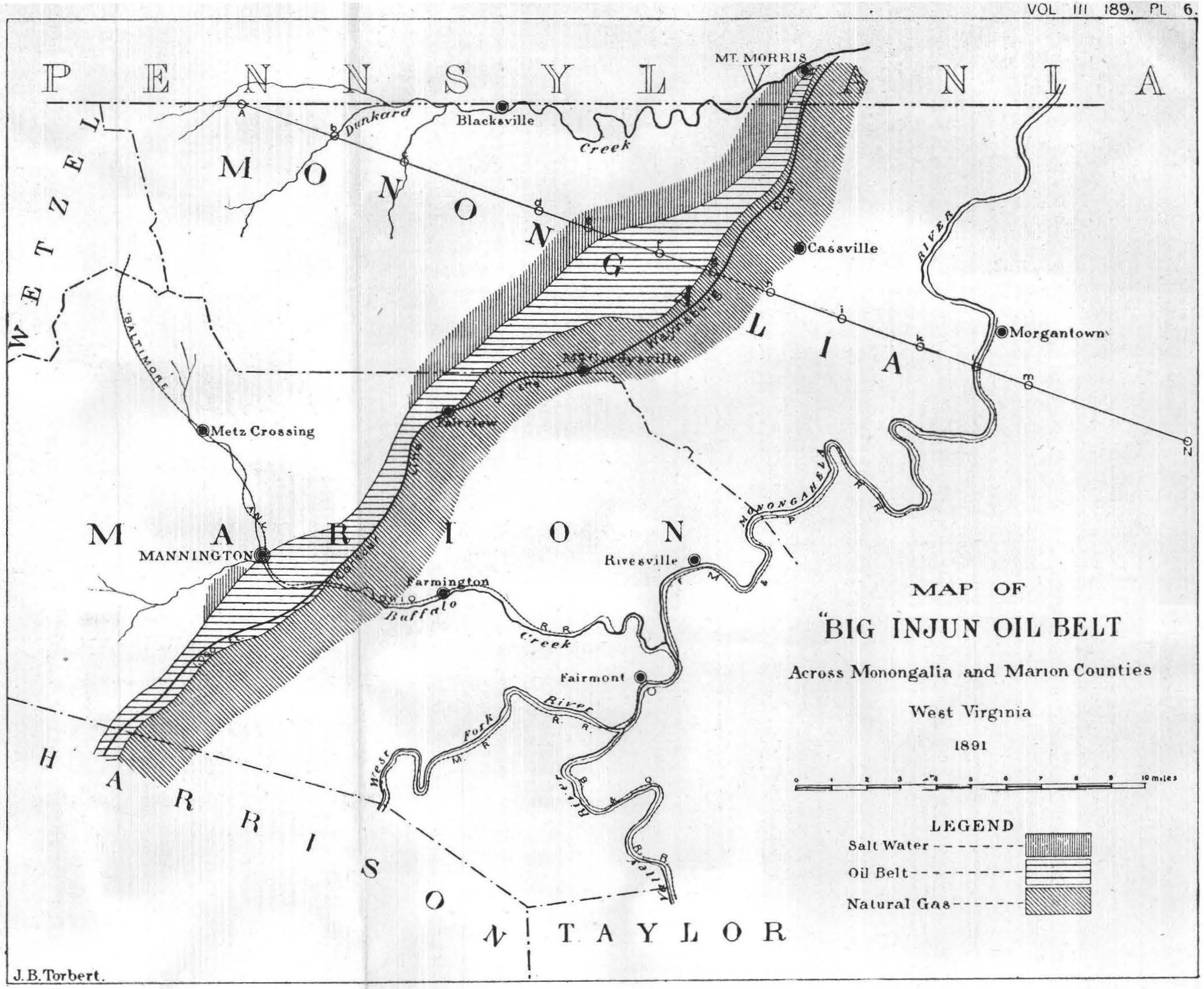
These plants were discovered and collected by Mr. W. F. Cummins, assistant on the Texas survey. They occur in the Wichita beds along with invertebrate remains which Dr. C. A. White has assigned to a Permain age, and vertebrate remains which Professor Cope asserts are of the same age. I was therefore quite anxious to know what answer the plants might give to the question of supposed geological equivalency between the Wichita series of deposits and those at the summit of the Carboniferous column in southwestern Pennsylvania and West Virginia and in southern Ohio, where the invertebrate and reptilian remains are absent, or at least not yet discovered, though plant remains are abundant.

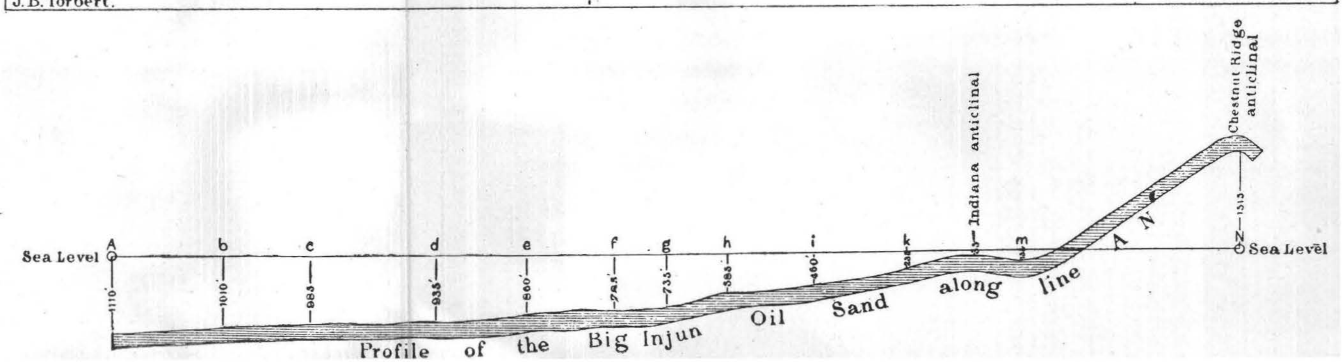
These West Virginia beds above the horizon of the Waynesburg coal had long ago (1878) been referred to the Permian by Professor Wm. M. Fontaine and myself,* upon the evidence of the fossil plants found therein; but as the correctness of this reference had been questioned, or at least not generally recognized by American geologists, the opportunity to compare this flora with that of a locality containing a Permian fauna, through the kindness of Mr. Dumble, was heartily welcomed.

After such cursory examination as I could give the plants when first received, I saw at a glance that they were either identical with, or very near relatives of, our West Virginia plants from the beds above the Waynesburg coal, and so wrote Mr. Dumble at the time. But to be certain of the matter, I sent the plants to Professor Wm. M. Fontaine, the distinguished paleobotanist at the university of Virginia, who at my request examined the collection and sent me the following list of identifiable species:

* PP, Pennsylvania Second Geological Survey.


MANNINGTON
FAIRVIEW
MT. MORRIS
Permo Carboniferous
Upper Coal Measures
Barren Measures
Lower Coal Measures
Pottsville Conglomerate
Mauch Chunk Shale
Mt. Limestone
Pocono Sand Stone or Big Injun Oil Sand
FEET


PENNSYLVANIA
MONONGALIA
MARION
HARRISON
TAYLOR
WETZEL
MT. MORRIS
Blacksville
Dunkard
Creek
Cassville
Morgantown
RIVER
Mt. Cudysville
Fairview
Metz Crossing
MANNINGTON
Farmington
Buffalo
Creek
Rivesville
MONONGAHELA
Fairmont
West Fork River
BALTIMORE
MAP OF
"BIG INJUN OIL BELT
Across Monongalia and Marion Counties
West Virginia
1891
LEGEND
Salt Water
Oil Belt
Natural Gas
J.B. Torbert.


Sea Level
A
b
c
d
e
f
g
h
i
k
m
Z
Indiana anticlinal
Chestnut Ridge anticlinal
Profile of the Big Injun Oil Sand along line A Z