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OF

DAVID WHITE

1862–1935

BY

CHARLES SCHUCHERT

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ACHIEVEMENTS IN BRIEF

David White came to the United States Geological Survey in 1886 as a draughtsman; he left it in 1935 as America's foremost authority on Paleozoic stratigraphy based on fossil plants, as her leading expert on the origin and evolution of those two plant products, peat and coal, and as the author of a theory of oil distribution that is basic to the petroleum industry. In addition, he achieved notable success as an administrator in the Survey and in the National Research Council, and he found time, withal, to be mentor and friend to hundreds whose affection for him found abundant and constant expression. As Mendenhall has so well said, "His was a career that came to full and happy fruition."

At the time White joined the Survey, and for some years afterward, there was marked conflict in America and in Europe between the correlations based on marine invertebrates and those based on plants, and there was lack of agreement even among the paleobotanists themselves, with the result that the correlations of the latter were usually accepted with reserve. Much of this conflict was due to the belief that the rate of plant evolution had been variable in the different regions. Sensing that the actual cause for the disputes was poor field work, White in 1893 said that it would not be possible to make trustworthy correlations on the basis of the Carboniferous plants until these had been studied as to "their exact stratigraphic occurrence. . . . It is not enough to collect and label fossil plants merely by localities; the flora of each horizon in the section should be collected and studied by itself."

This conviction of White's had been strengthened by his three summers' work (1890-1893) relabeling the Lacoe Col-

* In the preparation of this memorial, the writer has had the assistance of Miss Olive C. Postley, Mrs. David White, Doctor W. C. Mendenhall, and Doctor Marius R. Campbell.

lection, which contained 100,000 Carboniferous specimens, chiefly plants. By the time the task was completed, Campbell informed the writer, White had thoroughly satisfied himself that fossil plants could be depended upon for chronology and in geologic field work. White told the Director of the Survey about his conclusions, but Walcott insisted that, before anything was published, White should thoroughly test his conclusions in the field, where they could be checked by superposition. Following out this plan, White was assigned to Campbell's field party in the spring of 1893, and they continued to work together until 1895. From lithologic evidence, the Coal Measures sequence as determined in Pennsylvania had previously been thought to extend in its entirety into the central and southern portions of the Appalachian trough. Campbell, being doubtful of this method, adopted in 1896 the correlations determined by White on the basis of the fossil plants that he had collected. Regarding this field work of White's, Campbell in a letter to the writer says: "We all shared White's enthusiasm, and I soon decided that I would rather trust to White's decisions than to my own tracing of formation outcrops."

Finally, White, Campbell, and Mendenhall published memoirs in which the results were decidedly different from those previously presented. The correlations of White have prevailed, based as they are on the correct paleobotanic succession, and the leading exponent of the earlier view magnanimously said in 1904: "There is no conflict between stratigraphy and paleobotany respecting the main horizons. The conflict was but apparent, and was due solely to hasty correlations by the early observers." In later years, White held that his reputation as a stratigraphic paleontologist was based mainly upon his studies of these Pottsville floras. He revolutionized the general conception according to which the Pottsville, Allegheny, Conemaugh, Monongahela, and Dunkard (Permian) were supposed to continue down the entire length of the Appalachian trough, proving that all the Pennsylvanian beds in Alabama, probably exceeding 10,000 feet in thickness, the entire Pennsylvanian of Tennessee, and all but a rather small part of the northeastern Kentucky coal field are of Pottsville age.

From describing the Pennsylvanian floras and formations, White turned to the study of the origin and evolution of peats and coals, and soon became our foremost authority on this subject. From these deposits it was a natural step to the investigation of the origin and occurrence of petroleum, a study that led him to his famous hypothesis of the regional carbonization of Coal Measure strata, a theory which saved the oil companies millions of dollars that would otherwise have been spent in the drilling of dry wells. This "carbon ratio theory" is his greatest generalization, since it establishes a "dead line" beyond which oil pools will not be found. In the search for new oil territory in the years of the World War and afterward, White was of great service to his country. Finally, he was led to enter the field of geophysics, and he surprised the Fellows of the Geological Society of America in 1924 by taking, as the topic of his presidential address, "Gravity observations from the standpoint of the local geology." He was the first in this country to apply gravimetry to the detection of anticlinal structure.

Up to the summer of 1912, White's time was occupied almost entirely by research, and his results during that period are recorded in more than seventy-five reports, memoirs, and papers. However, he had served since 1907 as head of the Survey's Section of Eastern Coal Fields, and the breadth of interest and soundness of judgment there shown were fatal to his chances for uninterrupted research in so large an organization, and accordingly he was drafted in 1912 to become its Chief Geologist. For ten years he held this important post, and a strenuous decade it proved to be, because of the World War. But even during that period, when he was working late into the nights, he prepared more than a dozen scientific papers for publication. In response to his repeated urgings, he was relieved of direct administrative responsibility in 1922, with the expectation that his personal research could be immediately resumed, but soon other administrative calls were made by the Division of Geology and Geography of the National Research Council, of which he was general chairman for three years, as well as chairman of its Committee on Paleobotany from 1928 to 1934; and by the National Academy of Sciences, which he served as Home Secretary for eight years and as Vice-president for two years. He also served as Curator of Paleobotany in the United States National Museum. In consequence, his return to research in 1922 was nominal only.

The year 1930 had been highly productive in printed papers, and in the summer and autumn of that year White spent about two months in the Grand Canyon of Arizona and elsewhere at altitudes that were not beneficial to him, with the result that early in 1931 he suffered partial paralysis, and during most of that year lay between life and death. His strong constitution and his superb courage and optimism, however, once more put him back at his desk. His physical endurance was greatly diminished, but his mental powers continued unimpaired. How active he was during the next four years is shown by sixteen published and unpublished papers. He was at his desk on February sixth, 1935, but before dawn of the next day he had passed away in his sleep, death resulting from cerebral hemorrhage.

In his time, White published a little over two hundred reports, memoirs, papers, and notes, some of which will be analyzed on following pages. These relate to Paleozoic plants and stratigraphy (about 80 titles), coal (27), petroleum (39), "carbon ratio theory" (6), climates (9), biographies (6), and miscellaneous (36). Of Paleozoic plants he described or listed upward of one thousand forms, and of new species he named between one and two hundred.

David White was a member of the Geological Society of America (president 1923), the Paleontological Society (president 1909), the Society of Economic Geologists, the American Institute of Mining and Metallurgical Engineers, the Washington Academy of Sciences (president 1914), the Geological Society of Washington (president 1920), the Botanical Society of America, and the National Parks Association. He was elected to the National Academy of Sciences in 1912; was a member of the American Philosophical Society and the American Academy of Arts and Sciences; and an honorary member of the American Association of Petroleum Geologists, the London Institute of Petroleum Technologists, the Société Géologique de Belgique, and the Geological Society of China. He served at various times on more than twenty important committees of the National

Academy of Sciences, the National Research Council, and scientific societies.

He received the honorary degree of Doctor of Science from the Universities of Rochester and Cincinnati in 1924 and from Williams College the following year.

He was honored by the National Academy of Sciences with the award of its Mary Clark Thompson and Walcott gold medals, and by the Society of Economic Geologists with its Penrose gold medal; and in 1934 he was presented with the Boverton Redwood medal of the Institute of Petroleum Technologists of London.

We may well agree with Professor Berry's appraisal:

"No geologist of his time had a wider influence on the scientific life of the nation, or took a more active part in that of its capital."

ANCESTRY AND TRAINING

Charles David White was so christened at the wish of his mother, but from 1886 onward he preferred to be known simply as David White, that name being taken from his grandfather, Colonel David White (1785-1861), a pioneer and frontiersman, and a man of strong and somewhat eccentric character. His father, Asa Kendrick White (1817-1883), was born at Heath in northwestern Massachusetts, and later settled on a farm near Palmyra, New York. He was a descendant, through six removes, of John White (1602-1673), of South Petherton, Somersetshire, England, who, with his wife, Jean West, and their six children, came to New England and settled in Wenham (part of Salem) in 1638-1639. Miss Flora White of Plover Hill Farm, Heath, informed the writer that the White family was a virile one, producing farmers, educators, clergymen, and public officials, and has undergone but little change in characteristics and interests during the twelve generations since Thomas White, who died in England in 1549.

David White's mother was Elvira Foster (1820-1880), daughter of Hiram Foster (1794-1880) and Nancy Reeves. Her paternal line goes back through six generations to Christopher Foster, who sailed from London for America on June 17, 1635, with his wife and three children, was made a freeman at Boston in 1637, and in 1651 removed to Southampton, Long Island, where he was town clerk for thirty-two years. The Foster family is likewise one of energy and integrity.

David White was born July 1, 1862, on his father's farm in Palmyra township, Wayne County, New York, one mile south of the Marion town line on the road from Marion to East Palmyra. He was the youngest child of eight, six brothers and two sisters, all but one of whom attained the age of sixty or more. The family was Presbyterian, members of the church in East Palmyra. In Palmyra he attended the country school, in which at times an older brother or sister was a teacher. When he was eight or nine years old, the region received some hundreds of immigrants from Holland, among whom was Daniel Van Cruyningham, who worked as a hired man on the White farm but later graduated from the State Normal School and finally became principal of the Marion Collegiate Institute where David was receiving his college preparation. It was this man's wide intelligence and deep interest in the sciences that brought David, so he tells us, to the study of the flowering plants of the region and developed in him a deep interest in botany. One of his fellow students relates that David was a very tall, slender youth, who "always blushed as he arose to recite," that from the first he was considered an excellent student, and that as time passed he became popular with his classmates and the faculty.

Graduating from the Institute at the age of eighteen with much more Latin, Greek, and Trigonometry than was required for college entrance, White worked on the farm for two summers and taught school during the winters. Then, winning a county competitive scholarship at Cornell, he entered upon his college work in 1882. With the desire for learning implanted by his mother and a keen zest for science developed by Principal Van Cruyningham, he found in Cornell "most favorable conditions for growth in the liberal and stimulating atmosphere." The course pursued was then called Natural History, and included Botany. It required endless laboratory work of various kinds, leaving almost no time for athletics. The day was saved, however, by compulsory military drill for the first two years, to which White always acknowledged great indebtedness for the health and the erectness of stature so characteristic of him all through life. In the same class was Robert T. Hill, of Texas; both took the same courses, both became members of the United States Geological Survey after graduation, and both found their wives at Cornell!

White's study of Geology started in his sophomore year, with a general course given by Professor Samuel Gardner Williams. The next year he drifted into the classes of the widely known Professor Henry Shaler Williams, all of whose courses in Paleontology he pursued. At that time Doctor Charles S. Prosser, "a man of the highest personal character and scientific ideals," was laboratory instructor and assistant in the study of the Devonian invertebrate collections, to which the students of Paleontology were assigned for training. During field work with Prosser, White gathered numerous plantlike remains and in these he became particularly interested because of his love of systematic botany. Accordingly, when it became time to prepare the thesis then required for a bachelor's degree in science, he chose to make a thorough historical and systematic review of *Ptilophyton vanuxemi,* of which he had three thousand specimens collected from the shaly flags beneath the University campus.

This unpublished thesis, entitled "On the nature and systematic classification of Ptilophyton Vanuxemi," was loaned to the writer by the Cornell University Library. It consists of forty-five typewritten pages, with fifteen excellent pencil drawings of the fossils, made by White himself. This was his first attempt at scientific writing, and it shows that when he was twenty-three years old his methods of study and his style of presentation were already about as well developed as in later years. Even in those youthful years, he did not mind entering into a controversy with two of the paleontologic giants of that time, and we find him saying of *Ptilophyton vanuxemi:*

"It is evident that its present systematic classification is based principally on Morphology. Such being the case, it is not improbable that, paradoxical as it may seem, the species is still in a state of transition or migration; and, indeed, we do find it passing from one genus to another, disregarding all family ties, and vaulting from the animal to the vegetable kingdom, or from the vegetable to the animal kingdom, until we are uncertain whether it will turn up tomorrow morning devouring animalcules and small crustaceans as *plumulina plumaria,* or dreamily undulating in the crystal depths of ocean as *Ptilophyton vanuxemi.*"

In the end, he agreed neither with Hall, who maintained that *Plumulina plumaria* was a marine animal, nor with Dawson, who held that *Ptilophyton vanuxemi* was a land plant. In 1896, White returned to this study in a paper on "The structure and relations of Buthograptus, Plumulina and Ptilophyton from the North American Paleozoic," and then concluded that all of these are marine algæ related to the seaweeds.

In his junior year, White's father died, and, having almost no money, he borrowed a little from a friend, and with free tuition from his scholarship and with further money received for the teaching of elementary free-hand drawing, he got together the funds necessary to continue his course. He had unconsciously prepared himself for this teaching—and for still greater things to come—by taking free-hand drawing in his freshman year and by practise gained in the botanical and zoological laboratories.

The fifteen drawings made by White for his thesis kindled the interest of Henry Shaler Williams, with the result that when Lester F. Ward, of the United States Geological Survey, wrote to Williams to know if he had a student who could make "accurate if not creditable" drawings of fossil leaves, such as he needed in a study of the Laramie and Fort Union floras, Williams immediately recommended White. The latter started work for Ward in Washington on May 16, 1886, and was officially appointed to the Survey the following October. A vista of life now lay open before him, and his was to be "the quenchless spirit of the inveterate explorer."

With the assurance of permanent work ahead, White married, on February 2, 1888, Mary Elizabeth Houghton, of Worcester, Massachusetts. She also is of Colonial stock. Before their marriage she had been a student at Cornell, taking special courses in literature and history. His meeting with her at Cornell, White always considered the "greatest good fortune of my life," and to her he still remains a "knight without fear and without reproach." They had no children, but the lives of many young people have been enriched by their unconscious influence.

WHITE THE MAN

In appearance, David White was of commanding figure, six feet two inches tall, of an average weight of one hundred and eighty pounds, his blue eyes and blonde complexion bearing distinct evidence of his direct descent from Anglo-Saxon stock. He was ever alert and smiling. He met people easily, with ready and even voluble speech, and he possessed a charm of manner that made him a delightful companion, at home, in the office, or in the field. His sense of humor was subtle and delicate, often showing itself in sudden and evanescent flashes.

The instinct to help others seems to have been one of White's most deep-seated characteristics. It went beyond a willingness to lend a sympathetic ear, and sought at once for practical action. In recent years, he had come to be known as a special friend to the many expatriated Russians in this country, and he explained this interest by saying that he believed theirs had been one of the heaviest burdens left by the World War and that therefore they needed help most. At the end of his term of service as Chief Geologist, his old comrade Campbell said to him at a testimonial reception:

> "We all wish to show you our regard and affection which we feel for you as our Chief for ten of the most eventful years of the Survey's existence. We appreciate your unselfish devotion to duty as Chief Geologist, your helpful spirit of cooperation in all scientific matters, and your strict justice and impartiality towards us all of the Geologic Branch, but above all considerations of a technical or scientific character, we value most highly your spirit of love and goodwill for each and every member of the Branch. You have welded us together, as never before, into one large family and inspired us with the desire to do unto others as we would have them do unto us."

Mendenhall relates that White preferred to remain a government geologist to the end, even when offers came to him to enter the commercial field at several times the modest salary which the government pays its scientific leaders. In the nineties, the writer has been told, while White was doing work in the anthracite region, he noted that the lay of the rocks on one side of a valley, where coal was being abundantly mined, indicated synclinal structure. This being so, and if no faulting intervened, the coal beds should be repeated on the other side of the valley. Crossing over to test his conclusions, he saw that he was correct, and that here were buried millions of tons of anthracite unknown to the coal operators. What should he do? Resign from the Survey and turn real-estate promoter, or return to Washington and tell the Director of his discovery? He chose the latter alternative, and the facts were eventually published by the Survey. So White, preferring to remain loyal to the discovery of scientific truth, missed being a millionaire—a story the writer told to each succeeding class of his students as an example of the true spirit of scientific loyalty.

Mendenhall in his memorial says:

"White was given neither to underappreciation nor to overappreciation of self, he was wholesomely lacking in self-consciousness and always looked outward and forward, never inward or back. . . . In his philosophy life consisted wholly of opportunities to be made the most of, never of limitations to mourn over. . . . There was no resisting the infectiousness of his spirit."

Small wonder, with this combination of qualities, that David White was, as Berry says, "affectionately known to an incredibly large circle of friends and admirers."

WHITE AND GEOLOGIC CLIMATES

Some months after White joined the Survey, he began a compilation of the literature relating to Paleobotany, and a catalogue of the genera and species of fossil plants. Searching thus through the literature, he was led to write his first scientific publication, "Carboniferous glaciation in the southern and eastern hemispheres" (1889), a review that is written in a fluent style, marshaling the literature on a very interesting subject as if by a practised hand, and giving the status of the Glossopteris flora and of what is now called the Permian ice age of the Southern Hemisphere.

In subsequent years White wrote eight other papers on ancient climates, and made incidental remarks about this subject in many others. His second contribution of this nature was a joint effort with Knowlton, "Evidences of paleobotany as to geological climate" (1910). In his "Upper Paleozoic climate as indicated by fossil plants" (1925), he says that the late Devonian floras "were not highly diversified" but were "relatively highly organized," and remarkable for their wide distribution. The early Mississippian flora ranged even within the Arctic Circle, but the floras of the latter part of this period are not known to have been luxuriant, and they testify at times to aridity or semiaridity. In early Upper Carboniferous times there was a very rapid differentiation of land plants out of a few genera. In the middle and upper Pottsville (Westphalian) occurs "the most luxuriant and highly elaborated land vegetation of the Paleozoic era," at a time when there was maximum equability of climate over most of the earth. Later (in Allegheny time) seasonal changes set in, and in the Conemaugh and Monongahela there is "fairly clear evidence of lack of uniformity of distribution in rainfall throughout the year."

The Permian flora of Europe and North America shows

"signs of generally less equability and, in particular, of seasonal variation in climate, with clear evidence of deficiency of moisture in many regions. . . . The coming of dry seasons, and possibly of irregular periods of deficient rainfall in latest Pennsylvanian and especially in Permian time, led to the ascendancy of the coniferous stock. . . .

"Relative equability and mildness of climate and great latitudinal range of climate in relative uniformity are, geologically speaking, normal. . . . On the other hand, great climatic differentiation and variability, both seasonal and geographic, are abnormal, and are, I believe, confined for the most part to periods of diastrophic revolution, such as that in which we live" (pp. 471-473).

That diastrophism and the resulting geographic alterations are the main causation of marked climatic change is more fully stated in "Some cold waves of geologic history" (1926) and in "Geologic factors affecting and possibly controlling Pleistocene ice sheet development in North America" (1926). White thinks that the cooling was due to

"changes of level of the land, great reduction of the epicontinental seas, especially in the temperate and higher latitudes, the expansion of the continental surfaces, the corresponding differences in sub-oceanic topography, and the changes in ocean currents, air currents, rainfall and temperatures consequent to the changes in the land and water" (p. 69).

WHITE AS PALEOBOTANIST AND STRATIGRAPHER

In the summer of 1888, White made a collection of fossils, on his own account, at Gay Head off southern Massachusetts. Leaves, wood, invertebrates, and bones had been collected at this locality and written about ever since 1786, but since nearly all of the fossils had been picked up loose on the beach, geologists differed greatly as to the age of the strata. Most authors referred the beds to the Miocene, although some thought they saw Cretaceous fossils. After much persistent digging, White shipped to Washington "five barrels of very excellent material," nearly all of which he had taken out of definite horizons. On these he based his first stratigraphic paper, "On Cretaceous plants from Martha's Vineyard" (1890), which was illustrated by his own drawings. He concludes that the flora has "archaic types . . . unlike any that have yet been described." The relation of the Gay Head flora he found to be with that of the Middle Cretaceous (Cenomanian) of Greenland rather than with that of the Dakota group, and the plant assemblage is "largely identical with the flora of the Amboy clays." This paper was presented, with lantern slides, before the New York meeting of the Geological Society of America, with the great James Hall as presiding officer. In the *Bulletin* of the Society, we note that John S. Newberry, then the authority on Lower Cretaceous floras, commented that there could be no doubt about the Gay Head plants representing the Amboy clays and being of Middle Cretaceous age. Ward, White's chief at Washington, also agreed to the reference of the lower strata of Gay Head to the Cretaceous; when the paper appeared in print, Ward reviewed it in *Public Opinion,* and in a letter to the editors said:

"I am particular to have you know that the paper is wholly his [White's] own, and that I was unacquainted with its nature until I read of it in print. I have rarely enjoyed a more agreeable or complete surprise."

These high appraisals from leaders in Paleobotany must have pleased White and given him assurance for future work.

About 1892, a member of the Geological Survey of Missouri collected interesting plants from the Upper Carboniferous outliers flanking the Ozark uplift, and urged their prompt study, with the result that White was detailed by Ward to examine these plants not only in the laboratory but in the field as well, and to report on the findings. It was this detail by Ward that started White officially on his life work, namely, a thorough study of the Carboniferous floras of the United States. His first report was entitled "Flora of the outlying Carboniferous basins of southwestern Missouri" (1893), a work of 139 pages. The task came to full fruition in the memoir, "Fossil flora of the lower Coal Measures of Missouri" (1899), a monumental volume with 467 pages of text and 73 plates of plant illustrations.

In his "Age of the lower coals of Henry County, Missouri" (1897), White arrives at the following interesting results:

"The geographic distribution of the Mesocarboniferous floras throughout . . . Europe and Asia and North America . . . apparently indicate[s] an almost incredible uniformity in climate over the northern hemisphere during that period" and necessitates also "the assumption of such intercontinental relations and conditions as to furnish wonderful facilities for the exceedingly rapid, almost simultaneous, distribution of the genera and species" (pp. 302-303).

In 1904, White published his most philosophic paper, dealing with the stratigraphy of the Pottsville series throughout the Appalachian geosyncline ("Deposition of the Appalachian Pottsville"). The thickness is shown to be variable throughout the basin, being upward of 10,000 feet in Alabama, with the thickest deposits along the east side of the trough. The oldest Pottsville occurs on the West Virginia-Maryland-Virginia boundary, with the sedimentation spreading from here to the west and to the south (more quickly), and overlapping northward; in the bituminous region of Pennsylvania, Ohio, and northwestern West Virginia, there is no lower Pottsville at all.

White contemplated extensive monographs on the Pottsville and Mississippian floras, but these plans all had to be laid aside when he became Chief Geologist in the Survey. This necessity he always viewed "with very deep regret." The manuscript in hand, Director Mendenhall told the writer, consists of more than two thousand pages of systematic descriptions of over two hundred species of fossil plants, about seventy-five plates of illustrations, chiefly drawings, and over five hundred unmounted photographs. The Survey hopes to bring this work up to date and to publish it. Another monograph was in preparation on the Pottsville flora of Illinois; on it White did much work during the last three years of his life, and the Illinois Survey expects to publish it also. Still a third monograph, on the Pocono floras, is not so well advanced, but may come to publication.

In July, 1897, the writer and White accompanied Peary to western Greenland on the Newfoundland whaling ship, "Hope." The purpose of the expedition was to bring back a thirty-ton meteorite, now one of the most significant exhibits in the American Museum of Natural History. The two paleontologists were sent by the Smithsonian Institution, with instructions to spend the short open season of six weeks in collecting fossils, chiefly plants, which had long been known to occur in the Cretaceous and Cenozoic deposits of Disko Island and Nugsuak Peninsula. The results of their collecting were described in 1898.

On the return from Greenland, White and the writer left the ship at Sydney and proceeded to St. John, New Brunswick, to call on Doctor G. F. Matthew and to see the "Devonian" floras of the region, which were kept with the collections of the local natural history society. White was soon convinced, as he had previously surmised from the literature, that these plants are in reality of Upper Carboniferous time. This view had been set forth much earlier by Geinitz and by Kidston. Nevertheless, the Canadian Geological Survey continued to map the Carboniferous formations of the Bay of Fundy region as Middle Devonian. White published a strong protest ("Some palaeobotanical aspects of the Upper Palaeozoic in Nova Scotia," (1901), showing that the Horton flora is of Lower Carboniferous (Pocono) time, while those of the Riversdale, Mackays Head, and Harrington formations are of Upper Cariboniferous (Millstone Grit) age; and in "Stratigraphy versus paleontology in Nova Scotia" (1902) he stated that "over sixty percent of the valid plant species found at St. John [in the Fern Ledges] are also in hand from the Pottsville in the Appalachian trough."

White also wrote many papers on Permian, Devonian, and even Ordovician plants and stratigraphy. In his "Summary of fossil plants recorded from the Upper Carboniferous and Permian formations of Kansas" (1903), he for the first time uses the term Permian in the title of a paper, and records that in the Marion formation he finds plants "more nearly typical and characteristic of the Permian than any flora that I have yet seen from any other formation in the United States."

In 1904, he took up the subject of the Permian elements in the Dunkard flora, and states that of the 107 plant species he has seen, 22 are from the older Coal Measures of America and 28 are of the same age or of Permian age in Europe. In 1880, Fontaine and I. C. White had referred the entire Dunkard to the Permian, but David White regarded the strata below the lower Washington limestone as older than the Permian, while the higher part of the Dunkard, with *Callipteris,* he held to be equivalent to the Rotliegende of Germany. In 1926, he drew the boundary above the Waynesburg coal.

Previous to 1907, White had been studying the Permian Glossopteris flora of Brazil for I. C. White's "Relatorio Final," which was published in 1908, but a résumé of his results appeared the year before, in a paper called "Permo-Carboniferous climatic changes in South America." Both these studies are among the most important of those made by White. The Glossopteris flora of Brazil, with forty species, is correlated with that of the Talchir-Karharbari series of the Indian Peninsula. In the final quarto, White says that the

"cosmopolitan character and uniformity in distribution [of the Upper Carboniferous floras] forbid the admission of a glacial epoch between the base of the upper Carboniferous and the close of the upper Coal Measures, which marks the disappearance of many of the Coal Measures types. . . . For my own part, I am strongly disposed to regard the glaciation and approximate date of origin of the Gangamopteris [= Glossopteris] flora as not earlier than the orogenic movements and floral changes which ushered in the Permian" (p. 397).

One of White's most valuable papers, "Permian of western America from the paleobotanical standpoint" (1924), gives a review of the Permian throughout western North America. The Mid-Continent area of Kansas-Nebraska has "probably the most uninterrupted and complete Permian-Pennsylvanian section in all western America," he says in this article. The whole of the Council Grove formation is placed in the Permian, and the Neva limestone is regarded as making the base of the Permian system.

White's memoir on the Permian flora of the Hermit shale in the Grand Canyon (1929) is his most philosophic floral and environmental study, and is an indication of what he might have produced in more abundance had he not been bound down by administrative work. The Supai formation, long believed to be of Upper Carboniferous age, is here shown to belong to the Permian system. The Hermit flora "is largely unlike any flora known from the Lower Permian or the basal Upper Permian of any other part of the world;" no part of it is earlier than the Upper Rotliegende, and it is a heralding Zechstein assemblage.

His paper on "Some features of the American Permian" was presented to the Sixteenth International Geological Congress held in Washington in 1933, and reprints were published in 1934.

WHITE'S WORK ON THE NATURE OF COAL AND PETROLEUM

White's interest in the origin of coals began in 1893 with his field studies of fossil plants which he gathered at the coal mines, mainly in the Appalachian and the Eastern Interior regions. His special study in 1906 of the bedding conditions in a large number of coal fields of different ages in the east and west showed conclusively that ordinary coals were derived from woody terrestrial or carbohydrate tissues. He wrote at least twenty-seven papers on the origin of coal, beginning with a short note in 1907. In 1908, he defines coal as "a stratified carbonaceous deposit of first-hand organic débris in which the vegetable elements greatly predominate." The American coals were formed in situ under water on low lands, in peat swamps developed over old soils replete with roots of plants.

His most comprehensive and detailed report is "The origin of coal" (1913), a joint paper with Thiessen. Here he considers the geological relations and physiographic conditions attending the formation of coal, the rate of deposition, and the regional metamorphism. Coals are formed, he says, under

"(1) general mildness of temperature, approaching in most cases tropical or subtropical; (2) conspicuous equability or approximation to uniformity of climatic conditions, which, with a few exceptions, appear to have lacked cold winters or severe frosts; (3) a generally high humidity, the rainfall being from moderately heavy to very heavy and fairly well distributed through the year, though in many cases there is evidence of the occurrence of dry periods, which, however, seem ordinarily to have been comparatively short and not severe; (4) an amazingly wide geographical distribution of these genial and equable climates" (p. 68). Plants in swamps are reduced to coal by "(1) the biochemical process; and (2) the dynamochemical process" (p. 91).

In 1925, White returned to the theory of coal making in "Environmental conditions of deposition of coal." He does not subscribe to the popular idea that "mineral charcoal," the "mother of coal," or fusain, is of forest-fire origin and was later washed into the coal swamps, but holds that it is wood oxidized in the swamps while they were drying out under seasonal atmospheric exposure. The amount of fusain is so great and it is so variable in occurrence, he says, that it could not have been brought in by inwash from areas of forest fire without the accompaniment of great amounts of muds, which are not as a rule present where fusain is commonest.

As Chief Geologist of the Federal Survey, White became actively interested in the origin and nature of petroleum, and particularly in its regional distribution, and on these topics he wrote no fewer than forty-five papers. What he did during the years of the World War and afterward in directing the work of the Survey in the search for oil and gas, and in the elimination of waste in drilling, is well told by Miser in his memorial, and accordingly the subject need not be treated fully here.

In 1926, White brought together, for the *Treatise on Sedimentation* published by the National Research Council under the editorship of W. H. Twenhofel, the best account extant of the carbonaceous sediments, devoting fifty pages (eighty in the second edition, 1932) to their occurrence, sources, geochemical and dynamic changes, and other topics.

In "A source of hydrocarbons in the Ordovician" (1906), the Plattville shale of Wisconsin is shown to have about 30 per cent of volatile matter, composed of unicellular pelagic algæ, which appear to be related to living Protococcales. Such deposits are the probable source beds for the petroleum and gas now found in Paleozoic formations.

White's most noteworthy economic paper is "Outstanding features of petroleum development in America" (1935). In this Congressional Document, much of the gloom of earlier estimates as to the amount of petroleum still in the rocks is dispelled. "The aims of the wartime estimates of the country's petroleum reserves were educative," he says, and "the warning forecasts were designed to shatter the complacent obsession that the United States 'has all the oil it will ever need.' "

Another of his striking papers is "Effects of geophysical factors on the evolution of oil and coal" (1935). Petroleum, he says, is the joint product of

"(1) sedimentary deposits of organic mother substances of somewhat variable composition; (2) biochemical change of the mother substances, varying in kind and extent with the composition of the original organic matter and the conditions of deposition; and (3) geochemical changes which take place underground in the course of time under (4) geophysical influences, and which probably vary with the ratios of pressure, temperature, and time. Further, as found the oil may have been modified by leakage of its lighter components; by contamination; by reaction with associated inorganic as well as organic substances; by oxidation, and by filtration (pp. 309-310).

"The progressive carbonisation of the coal on a regional scale in any direction, accompanied as it is by progressive dehydration, lithification, refinement of cleavage, and increase of calorific value, represents incipient metamorphism; . . . it must be due to progressive geochemical change induced or even controlled by geodynamic influences, and . . . it embraces the essential features of the evolution of the deposit from the rank of peat, at which bacterial action is assumed to have been suspended, to the final graphitic residues and fixed gases if the process has gone far enough" (p. 301).

White's "Graphic methods of representing the regional metamorphism of coals" (1909) and his "Regional devolatilization of coal" (1910) are heralds of what has come to be known as his "carbon ratio theory"—that of the "oil dead line"—which is believed to be his greatest service in the field of economic geology. In 1909, he exhibited a contoured isocarb map of a portion of the Appalachian region, showing the degree of devolatilization resulting in the fixed carbon ratios of coal (free of ash and moisture) as one passes eastward from the western margin of the coal field (60 per cent about Pittsburgh) to the anthracite region, where it is 95 per cent. He held that deep-seated and long-continued thrust pressure of the coal—the greatest alteration marking the greatest pressure—resulted in great improvement in the bituminous coals. His "Regional alteration of oil shales" (1915) stated that no petroleum in commercial quantities occurs where the coals have 75 per cent of pure carbon.

That same year brought his famous paper on "Some relations in origin between coal and petroleum," his great contribution to petroleum finding, the subject matter of which he presented as his presidential address before the Washington Academy of Sciences. In it he dwells on the parallelism between oil (and gas) in particular and coal carbonization. Very little attention was apparently paid to the address by the geologic profession, and the conclusions received practically no acceptance until Myron L. Fuller some years later directed attention to them. It was, in fact, nearly ten years before the economic importance of White's conclusions was fully perceived by the petroleum geologists, and the annual waste lessened by drilling only in areas in which the carbonization was not distinctly too advanced. Due to the theoretical aspects of the problem, the relation between the advancing grade of the oil and the advancing carbonization of a region was slow to be accepted by the oil geologists. It is nevertheless indubitably true, as White pointed out, that in regions where the mother rocks are but slightly carbonized, as shown by the very low fixed carbon content in pure coals, the oils are apt to be of low rank, whereas in every case where we have to do with pools associated with or underlying coal-bearing formations of high carbonization, we have high-rank oils, the highest rank of all being found nearest to the "oil dead line."

Twenty years after White published his epochal paper on the carbon ratio, he returned to the subject in "Metamorphism of organic sediments and derived oils" (1935) and responded to the criticisms which followed the original publication. The extinction zone, or "oil dead line," he says,

"is found in many regions to fall in a zone narrower than at first defined and represents a carbonization (indicated by fixed carbon, pure coal basis) between 61 and 63 of the associated coals" (p. 589).

WHITE'S STUDIES OF PRE-CAMBRIAN ALGAE

Work in connection with a committee of the National Academy of Sciences which sought to develop public interest in the scientific aspects of the national parks led White to become interested in the most primitive known plant fossils, the lime-secreting algae of the Proterozoic formations of the Grand Canyon and Glacier National Park. Had he lived to complete the task thus entered upon, the results would have formed one of his major contributions. From 1926 to 1930, he spent a month or more each year in the national parks, under the sponsorship of the Carnegie Institution of Washington, and, as stated before, it was the effects of the high altitude of these regions, and the carrying of heavy sacks of specimens up steep slopes, that had much to do with his breakdown in 1931. In consequence of this breakdown, White was unable to bring his studies to a conclusion, but much of value is at hand that will at least show, when published, why he regarded these fossils as actual organic growths and not of concretionary origin. It was for this work that he received the Walcott Medal of the National Academy of Sciences in 1934. He had intended to etch many polished surfaces of the algae, to take collodion pulls from them, and then to photograph the microstructure, but this plan had to be laid aside. He had made, however, a large number of very excellent photographs of the algal masses.

From 1927 on, he published nine short papers on the subject of these ancient algae, which give some of his preliminary results; besides these, the Carnegie Institution has two manuscripts, totaling thirty-six pages, which were written in 1931 and 1933. What follows is taken from the manuscript of 1933 and the abstract published that year. In both papers, White combats vigorously the view of Walcott that but little or no marine strata occur in the Proterozoic, and he cites many places in various continents where limestones several thousand feet thick, and great masses of black carbonaceous shales, are known. Accordingly, he insists that "the burden of proof that the known Pre-Cambrian is entirely of fresh-water origin rests with the geologists who still hold to that view."

White's manuscript of 1931 confirms Walcott's discoveries as to the "plenitude of Proterozoic algae," and states that many more are yet to be discovered. He is convinced that these most archaic of fossils "leave no room for doubt as to the organic origin of most of the forms brought to light." As yet, his studies do not permit him to give descriptive details of the forms, but much of the structure is "clearly discernable under proper manipulation," and much microstructure awaits further study. In typical *Collenia,* the layers

"are composed of radiate nearly parallel slender tubes which were deposited on the probably gelatinous sheath of the algal thallus. . . . These successive growths . . . resemble nothing in the present-day flora so closely as the layers of *Lyngbya* and *Inactis* deposits. . . . In fact, the agreement between the Arizona and the recent deposits is most striking."

The late Proterozoic, he concludes, is clearly the Age of Cyanophyta.

White's scientific spirit is truly indicated in the following lines from Whittier's poem, *The prayer of Agassiz:*

"We are searching here to find
What the hieroglyphics mean
Of the unseen in the seen,
What the thought which underlies
Nature's masking and disguise."

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OF

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