COMPENDIUM OF THE GEOLOGY AND MINERALOGY OF INDIANA.

I.

GEOLOGY IN OUTLINE.

The surface geology of Indiana belongs mostly to the Drift, and is discussed in another part of this report; therefore the paleozoic rocks will chiefly claim our attention here.

Beginning with the southeastern part of the State and passing northward and westward, we shall find the outcrops in the following order:

THE HUDSON RIVER GROUP.

This group of the Lower Silurian is prominently exposed along the bluffs of the Ohio River in Dearborn County, and thence west to the mouth of Fourteen-mile Creek in Clark County. From this line northward it is found outcropping more or less in Switzerland, Ripley, Dearborn, Ohio, Franklin, Fayette, Wayne and Union counties, while in Rush, Jefferson, Clark and Decatur, and some other contiguous counties there are occasional deep-lying exposures, especially in ravines and the beds of streams.

The Hudson River rocks have also been called the Cincinnati group. They have been studied with exhaustive care by geologists, and their fossils, numerous and exceedingly interesting, have been the subject of some notable investigations by most distinguished scientists. Early in the history of Indiana the Ohio River became a base-line from which explorations in geology and natural history were made by a coterie of men whose names have become familiar to intelligent people the world over. So well, indeed, have the organic remains of our Lower Silurian rocks been examined and reported on that there would seem to be little left for the geologist and paleontologist to do in that field, so far as the exposures in the southern part of our State may be concerned.

The soil derived from the decomposition of the Hudson River rocks is, in the main, warm, rich and "lively," producing wonderful crops of corn, wheat and other cereals. Fruit trees, too, do well wherever the soil is well drained.

THE UPPER SILURIAN.

The rocks of the Upper Silurian have not been defined as well in Indiana as have those of the Lower Silurian; but they appear as the chief outcrops in Wabash, Miami, Wells, Huntington and Adams counties, and occupy parts of Jay, Grant, Blackford, Cass, Carroll, Jasper, Newton and White. They are exposed in parts of Delaware, Decatur, Hamilton, Henry, Hancock, Madison, Marion, Rush, Tipton, Bartholomew, Jefferson, Clark and Jennings, with a possible occasional outcrop in one or two other counties. The Niagara and the Clinton groups of the Upper Silurian may be studied to advantage at many points, notably the juncture of the Niagara and the Clinton in Fayette County, and in some of the adjoining counties.

Ball's Quarry, in Fayette County, according to Dr. Elrod, will show the Clinton limestone twenty feet thick lying in place between the Niagara and the Hudson River rocks. Indeed, all along the line upon which the Lower Niagara outcrops we may look for the Clinton just below.

The soils from the disintegration and decomposition of the Upper Silurian have been represented as "heavy clays," but my observation shows that often they are extremely light, easily drained, and very rich.

THE DEVONIAN.

The rocks of the Devonian age will be found outcropping in the peculiarly defined belt running from the Ohio River to the northern part of the State, and passing finally under the Drift deposits in Wabash, Miami, Cass, Jasper and White counties. The Devonian probably underlies a very large area of the extreme northern part of State, but owing to the great depth of the Drift deposits and the scarcity of borings, we can only conjecture its outlines. Its principal outcroppings are to be found in the following counties: Jefferson, Jennings, Bartholomew, Decatur, Rush, Shelby, Johnson, Tippecanoe, Cass, Wabash, Clark and Floyd counties, with occasional exposures in a number of other counties.

The Corniferous rock and the Genesee shale are the two members of the Devonian found in Indiana. The soil in Indiana formed from the decomposition of Devonian rocks compares favorably with those of other formations in the State.

LOWER CARBONIFEROUS.

That division of the Carboniferous age called the Lower Carboniferous, or Sub-Carboniferous, is composed in Indiana of the Knobstone, the Keokuk, the St. Louis and the Chester groups of rocks. It begins on the Ohio River in Harrison and Floyd counties and runs in a northwesterly direction through Washington, Orange, Crawford, Brown, Monroe, The Tertiary ages seem to have left no characteristic traces in Indiana, or if any of their deposits exist they are not exposed. The Drift mass in our State rests directly upon the paleozoic rocks, none of which appear to be of later formation than the upper Coal-Measures.

II.

A SKETCH OF THE SILURIAN ROCKS OF INDIANA.

The Hudson River group (or Cincinnati group) of the Lower Silurian may be studied to best advantage, perhaps, in the bluffs and ravines along the Ohio River in Dearborn, Clark and Floyd counties, though frequently exposures of a very interesting and characteristic nature will be found in most of the southeastern counties of the State.

Taking the Madison rocks as one of the typical Hudson River exposures in Indiana, we shall find them largely composed of strata, very thin, dark blue in color, crystalline, alternating with strata or layers of coarser texture, and much lighter in color.

The Marble Hill Quarry, six miles from the Ohio on the line of Jefferson County, affords a four-feet bed of fairly good building limestone, used in the court house at Louisville, Ky. Dr. D. D. Owen, remarking upon the beds of Marble Hill, says that they "consist of an immense accumulation of spiral marine univalves belonging to the fossil genus *murchisonia*." This so-called marble, though beautiful, has proved to be quite unfit for building purposes, save for interior ornamentation. For decorative mantles and tiles nothing could be finer. When cut and polished the ground of the stone is dark, clouded with the sections of fossils which give it a satin-like appearance.

In Dearborn and Ohio counties the Hudson River shales, of a bluish gray color, come to the surface, or are covered by Drift mass, which here, at its southern margin, is often fifty feet thick.

Near Richmond, in Wayne County, on the forks of White Water River, the rocks of the Hudson River group have been carefully studied by enthusiastic amateurs in geology and paleontology, to whom we are much indebted. The rocks here take on a buff color, shading into gray and blue, and are mostly shales, with many important fossil beds. A number of quarries are open, however, and some good building stone is taken out at various points in the county; but it is characteristic of the Lower Silurian limestones to weather badly on account of the oxidation of the iron they bear; hence it is rare that a first-class building stone can be found in the Hudson River rocks of Indiana.

The best fossil beds of the Lower Silurian are found in the weathered shale outcrops. Some localities near Richmond, in the banks of White

Water and its branches, have afforded fine collections, notably that of Mrs. Haines, while most of the counties of the extreme southeastern part of the State have similar fossiliferous exposures.

In Jefferson County the Hudson River rocks outcrop in Indian Creek in the form of shales and shelly limestones, with fine beds of characteristic fossils. Also in Decatur County there are exposures, mostly shales, from which Lower Silurian fossils are taken, mostly at the bottom of quarries begun in the Niagara rocks.

In Union County the blue limestones and marls of the Hudson River group are to be seen in a number of quarries, where the student and collector will be well rewarded, and especially are the blue marl partings rich in trilobites, most notable of which is the species *Calymene senaria.*

Perhaps the best place in the State to study the juncture of the Niagara and Hudson River rocks will be found on Laughery Creek, in Ripley County, where the stream often pretty accurately marks the dividing line. Below and above Versailles, on this stream, the Hudson River rocks present fine fossil beds from which many collections all over the world have been enriched with specimens.

The upheaval known as the Cincinnati Arch, running from near Sandusky, Ohio, to farther south than Nashville, Tenn., forms a datum line, from which our study of the Silurian deposits of Indiana may start. This anticlinal or ridge has been found to consist in Ohio of two folds. In Indiana, from a study of the Madison rocks and all the evidence gathered from the works of other geologists, I am inclined to place the exposures of Lower Silurian in our southeastern counties considerably west of the axial line of upheaval; but for the purposes I have in view, it does not matter whether "Cincinnati Arch," "Cincinnati Dome," or any other phrase is the correct one, or whether the arch itself is principally east or west of Cincinnati. It is sufficient that the Lower Silurian strata have been thrust to the surface along a certain line of upheaval, and that this disturbance, whether called local or general, has affected the geological conditions of Indiana in such a way that as we pass westward newer strata outcrop in succession until we have "run the gamut," so to speak, of the Paleozoic deposits (of the State) whose respective horizons are above that of the Hudson River group. It would require much more minute and patient investigation of all the discoverable facts than has yet been made by geologists of Ohio, Indiana and Kentucky to settle the question whether the so-called arch is or is not at certain points a series of truncated Lower Silurian folds, against the slopes of which in many places the superior rock deposits rest in place; but so far as Indiana is concerned we know that the Upper Silurian rocks succeed those of the Lower Silurian in the southeast part of the State, just in a manner to conclusively show that the former were deposited in a sea out of which the great Hud son River system rose as an island or low peninsula. Nearly all the strata of the Paleozoic rocks of Indiana dip westward, so that as we pass from the Lower Silurian to the Upper Silurian, thence to the Devonian and on to the Carboniferous, we find the strata outcropping in the form of a stair-like progression westward, while at the same time each stratum is dipping in that direction. This would seem to indicate one of two things: The entire body of deposits above the Hudson River rocks has been laid down on a slope which is a continuation of the west side of the Cincinnati anticlinal, or there has been a broad upheaval since the close of the Carboniferous ages. My own opinion is that the so-called Cincinnati Arch is but one of the manifestations of a great continental upheaval—a movement which was probably so slow that it continued through a vast space of time.

The Upper Silurian strata, consisting in this State chiefly of limestone, clays and shale, and exposed over a large area, present a field of study which will well repay much diligence and patient labor. Their examination may be begun almost exactly where a study of the Hudson River rocks ends, thus affording at the outset an invaluable means of comparative observation.

Along the Ohio River in Clark County the Upper Silurian is seen in the bluffs, where it occupies a narrow area; thence it runs eastward and northward into Jefferson County, where it begins to broaden. From Jefferson County northward to Miami, Wabash and Huntington counties it forms a very irregular strip, often flinging out on either side slender lines of exposure, but broadening, as a rule, all the way through Ripley, Jennings, Decatur, Franklin, Rush, Fayette, Henry and Wayne; thence northward it is bounded on the east by the Ohio line (so far as Indiana is concerned) and underlies the whole of Madison, Delaware, Randolph, Grant, Blackford, Jay, and nearly or quite the whole of Miami, Huntington and Adams. The Drift deposits are so thick in the northern part of the State that no definite limit can be fixed at present for the paleozoic rocks, but it is tolerably certain that the Upper Silurian covers nearly all the territory above indicated, with a probability that it underlies the Drift of Fulton, Allen and Whitley counties. Future examinations may extend the limit in a northwesterly direction, possibly. The Niagara rocks are exposed in so many localities that it would be far beyond the scope of this paper to particularize. From the Ohio River to Huntington, a distance compassing almost three-fourths of the State's length, characteristic fossils have been found more or less plentifully within most of the counties above mentioned. In the southern part of the Upper Silurian area Clinton fossils have been found, but the limits of that formation in Indiana have not yet been determined definitely. Professor Borden, in his report of an examination of Jefferson County for this Department, in 1874, states that, in the neighborhood of Saluda and Fourteen-mile creeks, the New Albany "black slate," the Niagara, the Clinton and Hudson River rocks all lie exposed within "a space of three miles." He also refers to the Clinton group twenty feet of "gray and yellow stratified sandstone" overlying the Hudson River formation in Clark County. Dr. Elrod reports the Clinton limestone twenty feet thick in Ball's Quarry, Fayette County.

The building stones and other economic features of the Niagara rocks will be considered in another part of this report.

III.

A SKETCH OF THE DEVONIAN ROCKS OF INDIANA.

The Devonian rocks in Indiana are exposed (or have been reached by borings) through a narrow, irregular belt lying immediately west of the Upper Silurian outcrops, and reaching from Floyd County, on the Ohio River, to Cass County, whence they probably spread over a great area in the north and northeastern part of the State, though deeply covered with glacial deposits. The strata of this formation are mostly limestones, black or grayish shales and clays.

What has been named the "black shale" (though not always black) is, perhaps, the equivalent of the Genesee shale. It forms the upper member of the Devonian in Indiana, and rests upon the Corniferous deposits, which, in turn, rest upon the Niagara. It is often the case that this shale is quite bituminous, wherefore it has been mistaken for "coal shale," causing persons unacquainted with geology to expend much time and money in vain, trying to "develop" what they have considered hidden wealth in coal mines.

The Devonian rocks are exposed, or may be reached by borings, in the following counties: Clark, Scott, Jefferson, Jennings, Bartholomew, Johnson, Shelby, Rush, Hancock, Marion, Henry, Hamilton, Clinton, Tipton, Howard, Carroll, Cass and Wabash, together with a large area of indefinite boundary over the northern and northeastern part of the State. It seems pretty well determined, despite the veil of drift which hinders examination, that the Devonian deposits are the uppermost paleozoic rocks over nearly or quite a third of Indiana's area.

The fossil beds of the Devonian in this State are almost entirely confined to the Corniferous formation, the black shales being, so far as I have been able to discover, practically barren. Professor G. K. Green, of New Albany, has collected and studied with more care, perhaps, than any one in the State the organic remains of the Devonian rocks, and to him we are indebted for a great deal of valuable information.

Some distance above Lafayette the Devonian shales outcrop in the bluff banks of the Wabash River, and thence along this stream northeastward nearly to Wabash County, there are occasional exposures of the limestones overlying the Niagara. Richard Owen reported a cutting of the Devonian rocks in Cass County, on the Cincinnati road. Southeast of Logansport another outcrop shows near the canal. On account of the scant exposures, the scarcity of fossils and the immense mass of drift which covers the strata, it is impossible to make out with any distinctness the northern dividing line between the Upper Silurian and the Devonian formations for some distance south of the Wabash River, but we may assume that near the northeastern corner of Tippecanoe County the approximate line of separation on the northwest, between the Devonian and the Lower Carboniferous, is discovered. Farther southward, however, the limits of all the formations are pretty sharply outlined. The western margin of the Devonian area is marked by the outcropping of the Knobstone (the lowest member of the subcarboniferous) in Johnson, Bartholomew, Jackson, Washington, Scott, Clark, Floyd and Harrison counties, from which line it reaches eastward to the western limit of the Niagara group.

In Decatur County many outcrops show clearly the contact of the Corniferous limestone with the Niagara rocks, and thence southward to the Ohio River, along an irregular line through Jennings, Jefferson and Clark counties, the eastern boundary of the Devonian area is pretty sharply marked by characteristic outcrops with the Niagara below.

The so-called "New Albany Black Shale," which is a well-defined member of the Devonian formation in Indiana, outcrops at New Albany on the Ohio River, and is exposed more or less throughout the Devonian area to as far north as the Wabash River above Lafayette. The testimony of the few fossils found in this shale scarcely amounts to evidence sufficient to identify it with the Genesee shale of New York, but it is probably true that the formations are equivalent. The dark color, amounting almost to jet blackness sometimes, which characterizes the New Albany shale, is due to carbonaceous matter in the form of bitumen and oil. Vegetable remains, consisting mostly of huge tree-trunks, are found imbedded in it, usually near the upper surface of the formation. These have been preserved by silicification, and their presence, to my mind, furnishes a suggestion of the source whence has been drawn all the combustible matter dispersed throughout the shale. At the close of the Devonian age the land was lifted above the sea and was clothed with dense forests and jungles. Then followed a period of submergence by which all the vegetable matter was covered with a thin layer of ferruginous limestone. The conditions not being favorable for the formation of coal, owing to the want of sufficient pressure, etc., the result was that a bituminous and oily residuum from the slowly distilled vegetable mass was filtered throughout the subjacent shales.

In 1875 Professor Whitfield, of New York, upon an examination of a few fossils from our Devonian shales, indicated his opinion that they should be referred to the "upper member of the Hamilton group." It appears to me that, indefinite as the above phrase is, it pretty safely defines the cloudy nature of our knowledge on this subject, to say the least. That the upper deposits of the Devonian age in Indiana were formed under conditions quite different from those attending the Hamilton deposits in New York is not to be doubted, however, and it is no more than the thoughtful geologist would expect, when we find that the few fossils as yet discovered in our particular Devonian shale are somewhat contradictory in their testimony.

IV.

A SKETCH OF THE SUB-CARBONIFEROUS ROCKS OF INDIANA.

In a slender area, immediately west of the Devonian, and stretching from the Ohio River to Newton County, the Knobstone group outcrops and comprises the lowest deposits of the Sub-Carboniferous age in Indiana. West of this and in due order and throughout practically parallel areas, the Keokuk, St. Louis and Chester groups follow. All these taken together make up the entire Sub-Carboniferous formation in Indiana, and may be considered collectively in this sketch.

Throughout its whole extent the Knobstone of Indiana is composed chiefly of sandstones and shales, the latter bearing a great deal of iron pyrites. The group is not rich in fossils as a rule. The sandstones are sometimes good building material, but not the best.

The Keokuk group, which immediately overlies the Knobstone, is in many places a rough, heavy-bedded limestone, alternating with cherty and clayey seams. Often, however, the limestone gives place to buff or blue or ash-gray shales, in which are found rich beds of fossils characteristic of the group. The famous crinoid beds of Crawfordsville are situated in these shales, which are, in that vicinity, mostly a pale sky-blue tint and quite soft when first exposed in the mine. At many points in the Keokuk area there is found, just above the Knobstone, a non-fossiliferous, dark blue, or sometimes ash-colored shale, which may possibly represent a trace of the Burlington group.

The St. Louis rocks, which lie next above the Keokuk, are largely composed of thin layers of moderately ferruginous limestone, massed in great beds with clay and concretionary partings, but shale is also common, with some excellent beds of fossils, thoroughly weathered out, so that cleaning is easy.

The best building stone in the State, the best in the world, in fact, is quarried from the St. Louis limestone wherever it takes on the oölitic structure. This justly famous stone is reported upon fully in another part of this work.

Next to the St. Louis limestone, and resting upon it, comes the Chester formation, composed of sandstone and shales to a large extent in its lower member, while in its upper member is the so-called Kaskaskia limestone.

The Chester sandstone is not very well stored with fossils, the most striking organic remains being stems of huge plants—boles of trees, roots and other vegetable fragments, such as *Sigillaria*, *Lepidodendron*, *Cordaites* and many obscure fucoidal markings. From this sandstone, passing up into the Kaskaskia limestone, we note a great change.

The sandstone appears to be the result of the breaking up of a comparatively short period of vegetable life succeeded by the Kaskaskian sea-deposits. The latter in our State marks the dividing line between the Sub-Carboniferous deposits and the true Coal-Measure rocks. Its fossils indicate a deep, quiet sea which, in the next age, was replaced by semi-tropical marshes and shallow waters filled with vast jungles of luxuriant vegetation.

This brings us to the point of swiftly sketching in the Coal-Measure rocks of Indiana.

V.

A SKETCH OF THE COAL-MEASURE ROCKS OF INDIANA.

The base of our Coal-Measure rocks is the Conglomerate sandstone formation which, in its typical state, is a massive, rather coarse-grained sand-rock, often pebbly and ferruginous, but affording in many places quarries of incomparably fine fire-proof building stone of varying and striking shades of colors. Wherever this rock is found the next step upward will be into the *locus* of some one of the coal-seams of which there are probably at least fourteen in Indiana, and possibly more. The Conglomerate sand-rock has been considered as forming the base of the Coal-Measures, but in Indiana, in fact, and at rare intervals elsewhere, seams of coal are found below it. Usually it may be identified by the quartz pebbles it contains and by the peculiar grit of its "texture," though it is often hard to distinguish it from other massive sandstones occurring higher up in the Coal-Measures. It may be studied to good advantage in all the northern counties of the coal fields, and along the southern and western limits of the Sub-Carboniferous areas, notably in Montgomery, Parke, Fountain and Warren counties. It varies a good deal in color, massiveness, "grain" and general consistency, but it must be known thoroughly before the Coal-Measures can be studied intelligently.

The Coal-Measure rocks cover an area of nearly seven thousand square miles in Indiana, while the actual workable coal fields cover more than six thousand square miles. The coal strata are separated by deposits, varying in thickness, of fire-clay, sandstone, shales of various kinds and limestones usually fossiliferous.

Each coal-seam is, as a rule, overlaid with bituminous shale and underlaid by a stratum of fire-clay. In the shale are found large numbers of fossil plants, while in the fire-clay are imbedded roots and stems of trees. Indeed, to the most casual observer, not in the least acquainted with geology, the vegetable origin of mineral coal will be apparent at once. Between the coal strata are interposed rock formations varying in thickness and structure, most of them more or less fossiliferous and indicating marine origin.

Geologists have found great difficulty in accounting for the phenomena connected with the formations of our coal fields. No doubt much trouble would have been removed long ago if details had been more closely studied and generalizations avoided. Especially is it true, here in Indiana, that nature has left her records in perfect order, written in the very simplest characters. Wherever we find a sedimentary rock in this State it lies just as it was deposited, as a general rule, especially in the Coal-Measures. It is true that, here and there, we may note signs of slight local disturbances, and in one instance, north of the Carboniferous area, a considerable displacement may be traced; but the larger fact is perfect simplicity and order, so that once the key is found the whole score may be read.

I think it safer to assume that the limestones, sandstones and shales have been formed of sediment deposited at the bottom of water. Geologists certainly agree here. The flora of the Coal-Measures would seem to be aquatic, semi-aquatic and swamp trees and plants. Hence, when we find coal deposits alternating with sedimentary rocks, we must conclude that a season or space of vegetation has been followed by a submergence in water. In other words, and simply stated, a coal seam, with its underlying fire-clay and overlying bituminous shale, marks a space of time when its area was covered with a growth of vegetation, while the stratified sedimentary rocks that overlie the coal denote a time during which sediment-bearing water covered the same area. Armed with these facts as keys, the geologist is ready to begin his examinations of our Coal-Measures. Now, if there be fourteen, or any other number, of our coal seams, with sedimentary rocks deposited between, we must conclude that there have been just as many periods of vegetable growth as there are coal seams, and just as many periods of submergence in water as there are sedimentary deposits. A few leading facts help us a great deal when they are clearly understood:

1. In the fire-clay underlying each coal-seam are found large and small fossil roots, stems, etc., of a strong vegetable growth.

2. The coal itself is a vast body of carbon, as if from the smothered burning of a mighty vegetable growth.

3. The overlying shales contain a mass of fossil vegetable forms, and also, in their upper members, marine animal remains appear.

4. In the sedimentary rocks of the Coal-Measures of Indiana the fossils are mostly marine, and belong in a large measure to genera extinct since the close of the Carboniferous age.

5. The Carboniferous sandstones often contain vegetable fossils, such as trunks, roots and branches of trees, among which are the *lepidodendron*, the *sigillaria*, *cordaites*, etc., while the limestones comparatively rarely bear any traces of vegetable remains. The Chester sandstone is particularly rich in fossil *calamites*.

Every observation of existing seas and lakes goes to show that very deep water is undisturbed at the bottom by even the greatest storms, wherefore it is at the bottom of very deep seas, or at the bottom of clear and stormless ones, if shallow, that we may assume that the purest limestones were formed, while, by a parity of reasoning, the sandstones and impure shales are the work of stormy or muddy and shallow waters.

It is of the first importance that we understand, in considering every geological problem, that length of time is not to be computed by days, months and years, but by hundreds of centuries, perhaps. Doubtless we shall never know what were the causes that operated to make the great changes necessary to advance and withdraw the seas during the paleozoic ages, so that large areas of dry land should become deep oceans and vast oceans become dry land, but we may be able to know that such causes have operated and that their effects are recorded in the rocks. It is idle for geologists to affect to reckon the years or centuries of years it has required to complete any ancient deposit. A single stratum of limestone but three feet thick, formed chiefly of infinitessimal shells, may have grown through thousands of years, by the falling of the cast-off crusts of dead animals, at the bottom of a deep, still sea. It is my opinion that the oölitic limestone of Indiana has been deposited by a process somewhat similar. So, too, the sedimentary rocks of the Middle Coal-Measures have no doubt occupied an immense space of time with their growth, each stratum of sandstone, each bed of shale or clay, and each limestone layer being the record of a period immensely long, reckoned as we now number years. With this view of geologic time we are prepared to comprehend in a degree the general scheme upon which our Carboniferous deposits have been laid down. It appears to me that we need not imagine sudden and terrible cataclysms in accounting for these alternations of land and sea over the same areas, but it may all be explained upon the principle of slowly creeping changes requiring vast spaces of time for their completion. Action and reaction are correlative physical phenomena observable in every stage and in every manifestation of force. The slow lifting of the sea bottom yonder will cause a slow overflowing of a sea coast here. Let us imagine the area of our western coal field as being at one time a low marshy shore of a great sea—a shore, for instance, not unlike the Gulf coast of Mississippi and Louisiana—covered with a wild jungle of vegetable growth, perhaps a hundred fold as dense and luxuriant as the wildest canebrake. Then suppose that by the slow uplifting of the bottom of the sea, far away perhaps, the water is made to rise by infinitessimal degrees, so that it keeps covering the roots and continually falling vegetable matter (through hundreds of centuries possibly), and at last it succeeds in submerging the whole carbonaceous accumulation and covering it deep under sedimentary deposits. The result is a coal-seam. Now let a depression of the sea bottom at some point slowly withdraw the water from our coal area again, and again will accumulate the dense brakes and jungles of vegetable growth until, at the end of a long period of time, the water again rises, and again covers the whole area deep in sediment. Here is another coal-seam, and so on. A careful study of our Carboniferous deposits can not fail to convince any student that they have been formed in just the way I have indicated. For instance, the evenly-bedded, fine-grained limestones, having been deposited at the bottom of a deep sea, bear a very small amount of vegetable material, while the sandstones, formed in a shallow, rough sea, do carry many vegetable remains. In my observations of shallow lakes and seas I have noted how floating logs, branches, weeds, foliage, etc., are often buried in the shore sands. For instance, Lake Okeechobee, in Southern Florida, at one time had upon its surface a floating raft of vegetable matter a mile long and averaging a half mile in width. The lake is very shallow, and at most points, when a wind storm strikes it, its water is lifted up almost bodily and tossed from one side of the shallow basin to the other. The vegetable raft I have spoken of was borne by a heavy gale to the shore and heaped up in a long "wind-row" where it was gradually, in the course of a few windy days, deeply bedded over with sand and other lacustral matter. Errant drift masses on the old seas could not form coal, they mostly rotted and disappeared, but a few chance scraps were preserved in the beds of shore sand, and are to-day found in our sandstones.

On the other hand, however, when the water encroached by the gradual advance of centuries, and with just sufficient movement to keep the wild swamp jungle's roots and falling matter covered and preserved, there was a continual, slow, steady accumulation of carbonaceous matter under just the right conditions for the formation of a mass which, so soon as the proper pressure was applied, became coal. This pressure was furnished when the sea at last prevailed and grew deep over the area and deposited heavy masses of sediment thereon, which in time hardened into stone.

It seems to me that every reason necessary can be given for assuming that our coal deposits covered an area which was, during the growth and accumulation of the vegetable matter, a low, flat, shore-marsh, not unlike that of our southern seashore at present. It will not do to look for evidence of local upheavals and depressions to account for the successive inundations and reappearances of the coal area. The uplifting of the sea-bottom thousands of miles away could have flooded a vast surface of flat shore, just as a sinking of a distant part of the sea-bottom could have uncovered the same surface. Now, remembering that these movements were almost infinitely slow (giving ample time for the accumulation of the coal-making vegetable matter) and that yet they were sufficient to finally submerge the whole and deposit rock-making sediment over it, we have before our minds a strong outline sketch of the method by which Nature patiently and surely wrought the wonders of our Coal-Measures. For we must admit that the amount of vegetable matter in a coal-seam three feet thick did not grow at once, or in a hundred or thousand years; but it accumulated by the ceaseless growing and falling of vegetation, all the time preserved by the water which increased sufficiently fast to keep the accumulations of carbonaceous matter covered from the destructive influences of the air.

The shales overlying our coal seams are clear evidence of the process above described. As the coal passes into shale, the record of the slow increase of the water's power is perfectly preserved. Clayey or stony sediment appears to be mixed with the vegetable remains, as if the sea-tides had begun to creep, with infinitessimally increasing volume, among the roots of the vegetable growth, letting fall traces of tide-mud to render the coal gradually more and more impure until finally the shells of marine animals begin to be deposited where once the coal flora flourished so luxuriantly, showing that at last the water has grown deep over the area and that vegetable life has been extinguished. There can be no doubt that this process of growth and inundation has been repeated as often as there are coal seams and intermediate rocks.

Prof. Lesquereux, whose attainments and whose opinions upon everything connected with vegetable paleontology are worthy of the highest respect, accounts for the formation of coal wholly upon what he calls the *peat-bog theory*. No doubt he is correct in this if he will refrain from confining the operation to mere lagoons or sheltered pools. Our coal-fields cover enormous areas and are the result of a mighty operation of Nature. I can not conceive how peat-bogs, such as Lesquereux describes and such as I have seen, could ever form coal like ours in Indiana. True, the process of peat-making is in a measure parallel with that I have sketched as the probable coal-making process; but our great carboniferous deposits can not, it appears to me, be accounted for on the theory that they were mere peat-bogs, or the result of floating vegetation grown in land-locked shore-waters. The silicious clays, in Indiana mostly fire-clays, that underlie the coal seams, are not diatomaceous, nor can I find any traces of sponge spicules in them. These clays are, in my opinion, formed of the fine sediment deposited at the bottom of a still sea whose water held the material in suspension. As the sea became shallow and its shores were converted into marshes somewhat similar to those of our southern coast, vegetation sprang out of this silicious clay. At first the growth was weak and small, no doubt, but at length it became a vast jungle, not unlike the great Dismal Swamp and the grand swamp wilderness of Florida and the Gulf coast. I have made my way through cypress swamps where the logs of fallen forests were so crossed and tangled and heaped together over hundreds of acres that I could scarcely climb over them or through them, and all these rested upon others buried or partly buried in the oozy, peaty mud. Evidently this mass of logs and old vegetable matter descended far below the ground surface. Indeed, it is a well-known fact that all around the Gulf coast there are buried forests and heavy deposits of peaty matter formed from vegetable masses long ago entombed in the earth.

It will not do for the arguments of the phytopaleontologist to be based altogether upon contemporaneous phenomena, however, for doubtless there have been great modifications of natural conditions since the times when coal vegetation flourished. Nevertheless, I would especially emphasize the following objection to the *peat-bog* theory of coal-formation when it is confined to land-locked lakes or lagoons: The perfectly clean and pure fire-clays, composed so largely of silica, could not be deposited at the bottom of muddy peat lakes or lagoons, where all manner of vegetable fiber, mold and refuse would be settling constantly; but such deposits might be formed at the bottom of still, clear water, which held silica (in a fine state of mechanical division) in suspension. The probability is that the silica, magnesia and alumina of the fire-clays came largely from the decomposition of older rocks, and were taken up, in suspension and solution, by the water (where it was agitated on rocky shores) and borne away to still places and let fall. Indeed the sorting power of water is marvelous. Our Drift deposits are full of instances of this power. For an example, take the peculiar clay deposit found in Kosciusko County, where the whole mass is a beautifully graduated series of assorted sediment.

From what I have seen in the course of a careful study of the roof-shales and under-shales of our coal-beds, I can not believe that the coal is the result of sphagnous growths, or that any appreciable part of its bulk could have been formed by the sinking of floating masses of any kind of water-plants. Coal so formed would be half mud—dirty in the extreme and but imperfectly combustible. The carbon of immense jungles piled one upon another throughout centuries and centuries of growth, and then submerged and covered with sea sediment, was required to make a four-foot seam of coal. No amount of pressure, I dare say, could make a pure quality of bituminous coal out of the ordinary peat deposits; still, the process by which peat is formed is a fair example of how Nature, even now, is entombing carbon by a method closely cognate to that by which ages ago she buried the coal forests. That the growth of the coal vegetation was preceded by still, shallow water over the coal area is evidenced by the clay deposit, and that it was succeeded, in each case, by a deep sea is proven by the marine fossils found in the overlying rocks. Indeed, every feature of our Coal-Measures points to the conclusions I have roughly outlined in the foregoing pages.

The amount of bitumen in the coals of Indiana, for instance, is so great that one can not imagine how it could have been a result of the ordinary peat-forming process. As I have suggested, pressure could not purify the mass; it could only render it solid—compact. The excess of mineral matter, left as the ash after coal has been burned, testifies to the deposition of foreign materials, that were suspended in the water in which the coal forests grew.

I have made careful search with the microscope, and have never been able to discover vegetable tissue in any genuine coal of the Carboniferous rocks, nor do I believe that vegetable tissue is at all discoverable there. Decomposition and incalcuable pressure have destroyed every trace of it. In the shales and in the lenticular shaly partings of our coals, however, I have discovered what appear to be myriads of spores. This suggests that impure, shaly places in coal may mark spots where for a time the surface was not sufficiently protected from the air, and, consequently, all the larger vegetable bodies were destroyed by rotting, and that these spores (doubtless of Lycopodiaceous plants) were preserved by being covered up in the mold. There are, in fact, comparatively few traces of any large plants in our coal shales, and I am inclined to think that the roof shales especially owe their vegetable matter in great part to ferns, mosses and other plants likely to spring up on the surface of such a great mass of fallen jungle growth as would subsequently form a coal seam. In the swamps of Michigan, where trout brooks sometimes run for many rods under wild heaps of fallen logs, ferns and moss, weeds and grass have grown over the mass until the annual falling and decay has formed a deep, treacherous mold that hides the whole from sight. This is a fair example of how Carboniferous shale was formed above the coal proper. When the sea came on and slowly covered the plants and mold with a sedimentary deposit the result was the roof shale, with its plant-impressions and its impure, bituminous, coal-like structure.

The shales pass by degrees into coal. This is partly on account of the increase of vegetable matter as we pass downward, and partly on account of pressure, which has tended to urge the bitumen to the lowest part of the mass during the process of formation.

When we consider for a moment the immense amount of vegetable matter, which is compressed into a workable coal seam, and the necessary mechanical and chemical changes wrought in the matter during the countless ages since it was deposited, we can not have much faith in microscopic examinations disclosing any reliable traces of vegetable tissue in the compact body of the coal itself.