THE DRIFT BEDS OF INDIANA.

CHAPTER I.

INTRODUCTORY.

In making the survey of Indiana it becomes more and more necessary, as the work progresses, to give a great deal of time to a study of the immense drift, or glacial deposits; for these deposits are, from both the scientific and the economical point of view, the most important of all the geological features of the State. The future of agriculture over three-fourths of our area depends, in a great degree, upon popular enlightenment touching the nature of our soils, and the best methods of improving and utilizing their productiveness. In a word, while it is not necessary for the farmer to trouble his mind in the least with technical geology, it is one of the absolute requirements of economic agriculture that he shall have an intelligent comprehension of the habits and demands of the plants he cultivates, and a fair knowledge of the nature and constitution of the soil he tills. A study of our drift deposits will disclose much more, however, than the wealth of soil which has made Indiana one of the greatest States in the Union; but the mineral contents of this immense glacial mass can scarcely have proper recognition until the demands of a rapidly increasing population force a closer scrutiny of its constituent parts. Necessity is more than the mother of invention, she is the enforcer of economy, she is the inspirer of experiment, the originator of improved methods of investigation. Slowly but surely the agencies are at work which will bring to the popular understanding, and within the control of the average man the wealth of economic materials heaped in the drift of Indiana.

In directing the survey of the State, it has been the chief aim to collect and group facts, and nothing has been neglected which could be made to serve this purpose. The great number of borings made all over the State since the examinations for natural gas were begun has given excellent opportunity for securing approximate cross-sections and longitudinal outlines of our drift deposits. With the aid of my able assistants, Prof.

Gorby, Dryer and W. H. Thompson, I have been given every facility to study the facts disclosed by these borings, and to bring together an amount of information hitherto unobtainable touching the extent and nature of the glacial deposits of Indiana.

In my last report (Fifteenth Report of the Department), will be found a full general description of the drift, with the accepted theory of its deposit by glacial agency, therefore it is not deemed necessary to return to that part of the subject at this time. It will be sufficient to point out how fully the borings have confirmed certain opinions I dared to hazard in advance of absolute knowledge. The existence of a grand moraine lying across central Indiana, as sketched in the paper above mentioned (see 15th Report), has been fully demonstrated by subsequent discoveries.

Professor Gorby has collected the facts in connection with the borings, and Mr. W. H. Thompson has continued the topographical and geological examinations of the Western Division, which includes the counties of White, Newton, Jasper, Pulaski, Carroll and Fulton, but a complete report upon these counties can not yet be made, and will have to be carried forward to the next volume. Upon the subject of the drift deposits, however, Mr. Thompson has furnished the Department with a mass of valuable facts which have been arranged and presented in the following chapters along with the results of my own examinations.

Some of the discoveries made in the drift by the borings for gas are peculiarly interesting, notably the existence of intercallated beds of fine white plastic clay in the body of the glacial till. This clay was at first pronounced by eminent authority to be kaolin; but upon examination I found it to be the result of selection and precipitation by water of silica, alumina and lime taken from the drift mass. Some of this clay contained as much as thirty per cent. of lime, while other examples held but a trace of calcareous matter.

An immense deposit of nearly pure white clay was penetrated by the drill at Lebanon, in Boone county. Both above and below this mass the drift till was very thick and compact. At Frankfort I saw evidences of the presence of this formation, but I could not ascertain at what depth the drill reached it or what was its thickness. Chalk, or lime marl, quite identical with that of the deposits described in the Fifteenth Report, is met with all through the body of the drift. At various depths strata of muck, soil, vegetable mold, fragments of wood, and some peaty deposits were passed through by the drill. The first well sunk at Frankfort was abandoned while the drill was in the bed of an ancient lake or pond, now filled with a slush of sand, loamy muck and vegetable remains, which was struck at the depth of about one hundred feet. The total thickness of the drift at Frankfort proved to be from 275 to nearly 300 feet. By reference to the tables of drift-borings in another part of this report the reader may, by the aid of a State map, locate the areas over which the glacial till is of greatest thickness, and the outlines of the vast moraines will become quite plain. The water-beds which afford the supply of water for more than two-thirds of Indiana's population are hermetically sealed basins of sand and gravel, inclosed in impermeable blue clay, commonly called hard-pan. In some of these basins water-gas (carburetted hydrogen) is found in small quantities, apparently generated from masses of vegetable matter shut up in the clay. This gas is very light, and the supply, from the nature of things, is never permanent. Frequently the water from the deeper of these sources flows with great force from the mouth of the drill-pipe, forming a gushing fountain. Usually the water of the flowing wells is impregnated more or less with salts of iron and the carbonate of lime held in suspension. The lime deposits itself in a fine white powder, whilst the iron is precipitated in the form of a red oxide painting whatever the water flows over.

One who has studied the cross-sections of the drift-mass at points where railroad cuttings and stream channels pass through will readily understand the value of the records obtained from our gas wells; but it is greatly to be regretted that so many of the drillers neglected or refused to keep accurate and minute notes during the progress of the boring, especially while the drill was in the clay and other drift deposits. The main object was to reach the Trenton limestone, and the chief thought was of gas. It was hard for the average well-borer to realize that any importance could attach to the materials through which his drill was cleaving its way. Still, by dint of untiring exertion, Professor Gorby succeeded in obtaining carefully verified records in a large majority of cases.

The contour of the drift mass is found to be comparatively regular in a general way along the line of the great moraine lying across central Indiana. Indubitable evidence everywhere exists showing that great local changes have taken place in the surface of this mass since it was deposited, changes which have all tended to level down inequalities and to bury deep under ground objects which once lay on or near the top. In Newton County a driven well at a depth of 70 feet reached vegetable loam in which were found the remains of leaves and plant-twigs. Over this county the drift depth is quite variable, the main body of the deposit lying around a cone of upheaval where the Niagara limestone outcrops with almost vertical strata. Careful study of hundreds of borings shows that the blue clay, known as till or hard-pan, is the only element of the drift which is genuinely persistent. The nature of this clay varies as regards the quantitative relations of its chief elements, and, consequently, its color oscillates between a pale ash-gray and a dark steel-blue, and shows every tint between those extremes. Wherever the mass is dark, soft and plastic it usually contains a large per cent. of silicia and alumina; where it is pale gray and refractory it holds more lime and crumbles readily upon exposure to the atmosphere. Under the microscope the minute particles of the drift clay clearly show that a wide variety of materials has contributed to the mighty grist ground to powder by the glaciers. Bits of coal-measure rock are found side by side with particles of hornblende, graphite, mica, feldspar and quartz, while pebbles of green-stone, polished like jewels, accompany angular fragments of silurian fossils, or worn crystals of calc-spar are side by side with minute fragments of magnetic iron ore. Even traces of gold dust here and there hold out a delusive hope to the ever present fortune hunter.

The soils of the drift present a curious and difficult study. Aside from the vegetable mold varying greatly in thickness, there is a heavy superficial coat of earth covering the drift proper, which presents many anomalous, and, in a great degree, inexplicable features. In some places, over wide areas, this soil has much the character of loess; in others it very closely resembles the residuary soils of Kentucky and Tennessee. Its depth is from one foot to ten feet, and its color is of every shade between black and a light drab, often showing beautiful tints of chocolate, yellow, brown and red. Among farmers it is known as sub-soil, but it is the true soil as distinguished from alluvial and vegetable loams, and upon its nature depends the value of the farming lands of all Northern and Central Indiana. In a general way it may be stated that if the soil is silicious it will be more or less "sour," heavy and wet, unless the silica preponderates in the form of sand, and where it is calcareous it will be light, easily aerated and very productive of corn, wheat, clover and other grasses. As a rule, beech and white oak forests grow on silicious lands, whilst maple, walnut and tulip trees prefer a calcareous soil, whose silica is in the form of sand, and whose deeper subsoil is gravel. Doubtless a great deal of the red and chocolate-colored clays of middle Indiana must be accounted for on the theory of lacustral deposition, but it is difficult to make many of the conditions agree with the requirements of such an assumption. For example, the so-called "modified loess" is most often found covering the highest points of the drift areas in which it occurs. It caps the hills of Montgomery County, south of Crawfordsville, is found on the high lands of Parke and Putnam counties, whilst farther south and east it may be distinguished without trouble in most cases by the trees which best flourish upon it. In almost every case where the deep subsoil is found to be a gravel bed, the soil will be a light brown calcareous loam bearing a heavy per cent. of fine sand. On the other hand, if a drab clay or hard-pan comes near the surface the soil is usually cold, and better suited to meadow than to cultivation in the cereals. Groves of white oak or beech usually cover these areas of "sour" land, but where a deposit of black mucky soil covers the drab clay, the burr-oak forests set in and mark a region, which, if drained, will always prove extremely fertile, as is shown by a large part of Boone County, which was formerly one vast burr-oak swamp, but is now one of the most valuable and beautiful agricultural areas in the State.

Most of the black prairie lands of Indiana are immediately underlaid with blue clay of the drift, but in Tippecanoe County much of the beautiful and incomparably fertile Wea country rests upon a vast bed of gravel and sand.

Superficial drainage is most valuable to the close, cold, silicious soils, especially to those where the blue clay of the drift comes to the surface over wide, almost level areas. Such soils, when once dried and properly aerated, produce enormous crops of timothy grass, making the most desirable hay in our markets. Indeed, in Indiana the one watch-word of our farmers should be: "Drain, drain, drain." No ditch which will bear away water can be laid amiss; every tile added to the drains of our farms is a step toward the age when Indiana shall be as well tilled as the best part of England.

CHAPTER II.

CHANGES AND MODIFICATIONS OF THE DRIFT SINCE ITS DEPOSITION.

If the great drift mass had remained unchanged from the time of its deposition to the present time, and if it could have been possible for us to examine it while it lay just as it was left by the mighty force which heaped it over the rock surface of Indiana, we should be in much better situation than we now are to understand the conditions under which it was transported from its original far northern resting-place and so distributed as to become at length one of the great centers of agriculture and one of the great highways of commerce and civilization. If, as has been claimed, soil and climate control in a large degree the destinies of mankind, it ought to be a very instructive and interesting task to solve, if possible, the conditions which have created the happy combination of a fine climate with a generous and inexhaustible soil. Although we probably never will do this entirely, we may at least reach a practical point of view from which we shall be able to determine all that is necessary to a full masterhood and a perfect enjoyment of our surroundings. Science is worse than worthless if it must be confined to theory and verbal jargon. Of what avail is mere knowledge? Wisdom, which is distilled from knowledge, is the essence of discovery. The study of minerals, fossils, soils and plants is of no value to the people of Indiana if such study does not bring to the popular mind the wisdom of economy, the enlightenment of intelligent masterhood of nature. Such wisdom is of slow growth, but it comes surely to an investigating people. Science sows its seeds, apparently at random, on stones and soil alike, but even in the crevices of the stones the germs find wherewith to sustain a valuable, if slender, life. It can not be said by even the most inveterate "fogy" that in mining, manufacture, transportation and agriculture there has been no access of wisdom from the investigations of science. The more knowledge acquired by the people as a body, the broader the foundation for popular wisdom.

It might appear, at first sight, a work without any practical purpose, for one to begin a study of the drift with a view to arriving at an idea of its form and general appearance immediately after the withdrawal of the great transporting glaciers; but any sincere mind will quickly discover that such an investigation goes before arriving at a competent understanding of the present condition of the subject.

If a glacier, or a succession of glaciers, transported to Indiana the immense mass of matter commonly called drift, there can be no question that an arctic temperature accompanied the glacial visitation, and we must suppose that the whole drift area, upon the retreat of the ice, was left bare, bleak, plantless and desolate, a waste of windy, barren till, traversed by rushing rivers, and dotted with lakes and ponds formed by the melting of the glaciers. I can not see how we can escape the conclusion that plant-life, save that of a boreal flora, was driven far southward of the Ohio River and that for centuries after the recession of the ice the drift area was practically without vegetation and the mighty moraines heaped up in vast billows of clay and bowlders lay exposed to the action of rain, frost, winds and heat, as the seasons passed, with no means of resistance save that of the natural cohesion of the mass. The action of frost and floods must have been very effective under such conditions. No trees, shrubs or grasses with roots to bind and hold the soil and clay together—nothing whatever to counteract the force of freezing and thawing or to check the washing of glacial currents and pouring deluges of rain. Moreover, in the dry seasons, when all the high lands were capped with dust, there was nothing to modify the effects of the winds, whose velocity at times must have been unimaginable. We see great and wonderfully rapid changes going on even now while the art of man and the binding forces of plant life are acting together to prevent them; but how much more rapid and radical must have been the changes under the conditions above suggested!

How long the drift mass lay, bare, bleak and unprotected, subject to all the elements of destruction and change, before the northward migration of plant life began to clothe it with a garment of resistance, can not be conjectured; but, as we now reckon time, it must have been a period too extended for us to have any adequate conception of its duration. Some geologists have attempted to reconcile the presence of the glaciers with a climate almost temperate; but to my mind such a condition is inconceivable. While it is true that glaciers, like those of the Alps, local and inconsiderable as compared with those of Greenland, are found within a temperate area, there can be no doubt that the advent of a body of ice sufficient to plow down granite hills and thrust forth over a large part of North America a mass of till averaging many feet in depth would reduce the temperature of the region affected to arctic severity. In other words, if at present a mighty glacier, hundreds of feet in depth, extended from the region of the Rocky Mountains to the Atlantic coast, and from the latitude of Greenland to that of the Ohio River, its effect would be to change the climate of the southern part of North America from a temperate, sub-tropical and tropical one to a cold, changeable sub-boreal one, and to drive out all plant life save that which can bear the rigid conditions attending such a temperature. How slow would be the return of vegetation to the cold clay region of the drift, after the retreat of the glaciers, may be imagined. At best, under the most favorable conditions of climate and soil, the northward migration of plants is extremely difficult and faltering. But the drift as left by the ice was a clammy mass of clay, without soil, wholly unsuited to the rapid spread of vegetation. We may, therefore, safely assume that for many hundreds, and perhaps thousands, of years after the retreat of the glaciers the drift mass lay exposed to every force of nature without any protection whatever, and underwent every change consequent to such exposure. What would naturally be the result? Speaking generally, we should answer: The result would be a grand leveling process by which the high parts of the drift mass would be reduced by the action of freezing and thawing, the washing of rains and force of winds, and by which the hollows and low places would be filled up apace. Thus old glacial channels would be gradually buried under the materials washed and blown down from the high ridges of moraine matter on either side, lakes and ponds would be filled up by the same process and in the course of centuries a mighty change would take place in the surface configuration of the drift. It matters not how many so-called "periods" of glacial action there may have been, the fact remains that at least there was a final retreat of the ice after which the process of change would have gone on as I have suggested.

As the reduction of the high parts of the great moraines went on the mighty ruts, channels and basins between were gradually obliterated by the filling process, and the whole drift mass took on the comparatively level or broadly undulate surface which now characterizes it. Meantime the well-known assorting power of water and the action of wind in transporting vast bodies of sand were continually at work, so that it is easy to account for many of the gravel beds and bodies of sand and assorted clays found deeply buried in the body of the drift.

At first glance it is surprising to find that ridges of pure sand and conical mounds of clean gravel have withstood the action of frost and water much better than formations of the most refractory hard-pan, but a little consideration explains the apparent contradiction of facts, for water percolates through sand and gravel instead of washing them away, while it must run over the clay and slowly, but surely wear it down. So the action of frost is lost upon the loose particles of sand and gravel, though clay is disintegrated and reduced to dust by it. Hence, it is that the so-called "kames" and "dunes" are the best preserved features left to us of the original drift forms, and they should, therefore, be studied with great care.

One of the most hopeless features of the work now being done by the most enthusiastic and well known students of the drift is the determination to ignore the changes of which I have spoken. No where in the reports, official or private, have geologists appeared to fully comprehend that the drift has not lain, just as it now lies, ever since it was abandoned by the glaciers. If a bit of wood or a wisp of leaves is found ten, or fifty, or a hundred feet below the surface of the ground, they take it for granted beyond cavil, that it was buried there by the glacier, never for a moment considering that the filling up of a hollow by the wash from higher ground may have caused the burial. If a wide area of drift surface is comparatively level now, they conclude that it was just so when the glacier left it. If they can not find in the moraines of Indiana, Ohio and Illinois, every feature of the moraines of the Alps, they shake their heads and say: "There are no moraines." To my mind the study of our glacial area which does not begin with a recognition of the wide and deep changes which were wrought in the drift mass subsequent to the retreat of the ice and prior to the return of vegetation in its present form, is worse than futile. We must understand the fact, and accept it fully to begin with, that the *drift as it is now*, is greatly modified from the *drift as it was when it was fresh from the plow-share of the glacier*. We can not know all the changes nor their extent, but we can and must know that nature has not rested idle for thousands of years in order to leave undisturbed (for the accommodation of scientists) the most easily disturbed of all our geological formations.

It is safe, at least, to take it for granted that the high parts of the drift mass were formerly much higher and the low parts much lower than they now are, and from this fact we may argue that a great many features that now are internal elements of the drift were formerly external ones, and *vice versa*. Where streams have cut deep into the body of the drift it may be observed frequently that the semi-stratified sands and clays are bent or curved, as if somewhat folded by pressure. In many cases this arrangement is due to the washing-down and filling-up process which I have described, each stratum in the series representing the extent of a season's or other cycle's contribution to the lower plane of what it has taken from the higher.

Bearing the above in mind, the student of the drift will be able to distinguish approximately between that part of the mass which is undisturbed and that which is a modification of the original formation. As a rule the highest points will be more likely to be found unchanged in the structure than the lower ones. Of course, the former will be worn down indefinitely, but the material remaining will be in place practically as left by the glacier, while on the latter will be found the washings of centuries of floods, the blowings of centuries of winds and the crumblings of centuries of frosts.

It is then on the highest parts of the drift mass, at points where, from the nature of the surroundings, no great changes could have been effected, that we should look for the true characteristics of the glacial moraine. These points are comparatively few, but when found are extremely interesting Usually they are capped with a boulder field, or they have cones and ridges of gravel and sand to mark a resting place of the glacier's foot at that time when the great ice fields were slowly and with much hesitation retiring into the north. Geologists have, in my opinion, made a great mistake in naming these undisturbed spaces "areas of erosion." They are in fact areas of drift mass remaining, with slight superficial changes, just as the glacier left them, and they usually mark the stranding places of boulder-ladened icebergs and the turning and eddying points of sub-glacial rivers.

On these high areas there are found also many small, undrained basins, the remnants of deep pot-holes which have not been entirely filled up by the leveling process above described. Usually these basins have a subterraneous drain by means of underlying sand or gravel beds, though this is by no means always the case, for I have found them with impervious blue clay bottoms, and they were ponds during all but the dryest seasons.

The changes suggested in the foregoing pages are still going on in a limited way, and it is one of the trials of enlightened agriculture, this battle against the tendency of soil to slip down from the high levels, to wash away, in fact, and leave our very best lands impoverished.

CHAPTER III.

FORCE AND DIRECTION OF THE GLACIERS.

In Indiana the general direction of the glacial movement was a little west of south. There are localities in the State where the *striæ* or sand-marks on the ice-ground rocks run from east to west, and in almost every other horizontal direction; but by careful study these are found to be merely local exceptions to the great general rule. Much confusion and misconception have arisen out of the acceptance (as of conclusive authority) of certain maps and reports of the United States geological survey purporting to define, only in a provisional way, the directions of the glacial *striæ* in the northern part of Indiana. I do not intend personal criticism here, for this would be unjust, and I must not be so understood as to make my words mean any stricture upon the integrity of any person, or upon the general value of any report; but I do wish to say as plainly as words can convey without conveying anything but the friendliest dissent from a theory, that there is no competent evidence whatever of a distinct and separate "second glacial epoch" in Indiana, and that there is no adequate evidence in support of the assumption that the drift of eastern Indiana came from the Lake Erie region, or from any other region much to the eastward of a line drawn north and south through the drift as it now lies. The glacial deposits of Indiana by their conformation, by the materials found in their mass and by the *striæ* underlying them, have come into the State from a direction almost north and south. The internal structure of the drift mass shows conclusively that there have been innumerable local advances and retreats of small lobes or parts of the glaciers, and that there have been many general forward and backward movements of the ice-field as a whole, but there is no evidence pointing with any force to two distinct "glacial epochs." Indeed, the drift deposits conform precisely to the conditions one would naturally expect to find accompanying glacial action of such enormous proportions as that which was able to produce the results at present visible to any casual observer of the area affected.

Glacial *striæ* on the face of rocks known to be in place are not the best evidence of the direction in which the ice-mass *as a whole* may have traveled, and it is injudicious to assume that *striæ* four inches, or four or five feet long, speak conclusively on this point. The exposures of ice-planed rock-surfaces are few and far between in the true drift area. It can not be said that fluid ice alone, of all the fluid substances, flows in a straight line, come what may to hinder or avert. I have seen *striæ* crossing *striæ* on the same rock surface and at almost right angles. Could such testimony be taken as conclusive evidence of two glacial epochs? If so, the later epoch must have been one of very slight power, else its grinding would have obliterated entirely the mere scratches left on the rock by the earlier one! If the first "glacial epoch" was charged with a force that ground down the granite heights of Canada and dashed their till over a vast area, how insignificant must have been the power of the "second glacial epoch" if it could not even obliterate hair-line scratches left by the first on the top of a moderately soft limestone, especially when acting in quite a different direction from that of its predecessor! That the great glaciers came down from their northern fastnesses in billow succeeding billow, a sea of elastic and flexible ice, advancing, retreating, weltering like any other sea, save that all its motions were almost infinitely slow, and rolling on down to its limit, then withdrawing by the same oscillating and faltering process—that all this is true can not be doubted; but this process had nothing in common with two distinct and separate epochs; it was all included in one epoch of drift-making. Doubtless the ice came and went many times, pushing forward and withdrawing partially or wholly from certain areas, until at last it went away forever. There is every evidence in the body of the drift of these oscillations of the great ice pendulum. We can not even conjecture intelligently as to the duration of any advance or withdrawal. From top to bottom of the drift deposits, as shown by the borings for gas and as indicated by every section made by streams, railroads or domestic wells, the mass has a rude system of stratification or lamination in its structure caused by this tide-like motion of the glacial body. Such a motion, the palpitations of which were measured each by centuries, perhaps, could not fail to leave apparently contradictory records in the form of *striæ* on rock-surfaces in different localities.

At Huntington, Marion, Wabash, Kokomo, Logansport, Delphi, Monon and Kentland I have examined *striæ*, and they have been almost exactly parallel in direction, running a little west of south. At Darlington the well-preserved *striæ* are in continuation of this line; but southwest of Crawfordsville I found them running in three directions, southeast, almost east and due south, whilst a little further north on Sugar Creek, and along Black Creek, they conformed exactly with those at Darlington. Near Darlington, however, not far from the bridge of the T. H. & I. R. R. over Sugar Creek, there were *striæ* that appeared to run almost due west. Near Mace (in Montgomery County) there were some obscure marking that indicated a southeastward movement. In Putnam and Parke Counties the *striæ* lie nearly in a north and south line, as they also do near Williamsport, in Warren County, if certain coarse grooves in the sandstone may be accredited. I mention these apparent contradictions in the testimony of the *striæ* to show that isolated cases must not be accepted as even *prima facie* evidence of the *general* direction of the glacial current.

To my mind, the best evidence of the axis of the force which propelled this drift mass lies in the form of the waves of resistance still visible in that mass. In driving a plow across a field the observer notes that the form of the plow-blade and the direction of its movement give form to the waves of resistance offered by the soil. The same is true, in a general way, of any force acting upon a yielding substance; the substance arranges itself in front of the force in a wave of resistance which outlines pretty accurately the direction and nature of that force. Lying across Indiana in practically parallel lines, waves of resistance are clearly traceable in the drift, and these waves all are practically parallel with the southern shore-line of Lake Michigan. The process of leveling described in another chapter has obliterated the superficial outlines of the moraines;

but the gas-well bores have pointed out with reasonable certainty in the mass the direction and extent of those formations.

The surface features of the paleazoic rocks of Indiana were a factor of no small importance in directing and controlling the current of the glacial body. The great disturbance named by Professor Gorby, the *Wabash Arch*, lay directly across the path of the ice, offering a very refractory and persistent barrier to its progress. In surmounting this the glacier was deflected to the westward, the point of one lobe resting at Logansport, while another cut through from Delphi to Lafayette, thus determining the course of the Lower Wabash. This whole rock disturbance in Indiana occurred at the close of the Niagara period, as is shown in another part of this report, and it was only in the lowest parts of its area that any superior formations were deposited. Hence very few fossils whose horizon is above the water-lime are found in the drift immediately south of the Wabash arch.

Wherever the Niagara rocks are exposed at the surface in the area of this disturbance they are apt to show signs of glacial grinding. At Kentland (McKee's quarry) where the strata outcrop almost vertically, the edges of the limestone layers are very plainly marked with grooves and *striæ*. In White County, where there is a heavy outcrop of Devonian shale, the upper stratum of the hard bluish, black rock is finely planed and grooved, the *striæ* running nearly north and south.

The survey has not progressed far enough North to permit me to speak of the moraine provisionally mapped out by Professor T. C. Chamberlain as lying parallel with the south shore of Lake Michigan, and having for points in its line Joliet, Illinois, Valparaiso and Laporte Indiana, and Niles, Michigan, but from some hasty preliminary examinations I am inclined to think that the nature of that formation is not yet properly understood. It appears to me that wind probably has had more to do with certain features of the formation than the glacier had, though there is no doubt as to the morainic character of the main mass.

So far as examinations may be relied upon at this time, it appears that the glacial trough has its greatest depth in the great lakes, and that it gradually shallows southward in a general way; but the Wabash Arch lies across it, midway between Lake Michigan and its southern confine, greatly modifying its form.

From Wabash to Delphi the Wabash up-lift has determined the course of the Wabash River, just as it also determined the form of the drift mass immediately south of it. The river itself is running along the general line of a wide fracture or system of fissures in the Niagara rocks from Wabash to Logansport. At the latter place it has cut through a spur of the Devonian formation, and at Delphi it curves around the base of a curious conical up-lift of the Niagara limestone. To my mind it is plain that the river simply follows the example of the ice current which went before it plowing out the great furrow which we call the Wabash Valley. At present evidence is wanting to prove any theory as to what particular part of the glacial age was devoted to the work of channeling out a groove for Indiana's greatest river, but it would appear that this must have been the first result of the glacier's contact with the low but compact and stubborn knobs of the Wabash Arch. Subsequently, as the ice field grew in weight and power it arose and surmounted this barrier, grinding away its conical peaks and tearing out of its hollows in many places the non-conformable Devonian and Carboniferous rocks.

The drift covers most of the area affected by the Wabash Arch, but the drill has disclosed ample evidence to sustain the main conclusions reached by Professor Gorby and myself as set forth in the Fifteenth Report. In passing over this wide, low, billowy area of upheaval the ice currents must have ground down the highest points of the Niagara rocks, but enough of the inequalities of surface remains to show the nature and extent of the disturbance, which runs entirely across the State, its northern limit passing from some point between Union City and Fort Wayne across in a generally westward course to Kentland. Both North and South of this line strata superior to the Niagara formation appear, abutting against the slopes of the upheaval, showing that the ridge was above water at the time that the Devonian and later rocks were being deposited.

By taking the slopes of the truncated Niagara cone at Kentland I calculated that, if the arch was once perfect, the glacier must have cut away nearly a hundred feet of that upheaval. Nearly as much was removed from the beautifully symmetrical arch at Delphi.

CHAPTER IV.

DEPTH AND STRUCTURE OF THE DRIFT MASS IN INDIANA.

Up to the time when the search for natural gas began in Indiana, we could only conjecture as to the depth of our drift mass. The many wells sunk within the last two years have enabled us to construct approximate cross sections, and to outline the areas of thickest deposit.

Below are given some tables of drift depths from which many useful and instructive facts may be gathered. Table No. 1 contains the thickness of the drift mass at all the chief points along the course of the great central moraine described in the Fifteenth Report of this Department.

TABLE No. 1.

	Depth of Drift.
Kentland	100 feet.
Oxford	385 "
Monticello	205 "
Frankfort	297 "
Noblesville	73 "
Lebanon	300 "
Crawfordsville	140 "
Haughville	123 "
Broad Ripple	55 "
Knightstown	64 "
Winchester	116 "
Shelbyville	78 "
Greenfield	205 "
Rushville	60 "
New Castle	333 "
Union City	98 "

The above table shows that although the western limb of the moraine is somewhat heavier than the eastern one, the mass is remarkably balanced. It must not be overlooked, however, that the gas wells are not always a fair test of the thickness of the drift, as they are sometimes bored in depressions with a view to finding the nearest route to the hard rock below. Carroll county, for instance, is heavily covered with drift, but the gas well at Delphi, owing to the fact that it was sunk at the apex of a fold, shows scarcely any deposit above the Niagara rock. From Indianapolis southward White River breaks through the central point (the apex angle) of the moraine, which here turns northward of an east and west line in both directions, forming across the State a figure in the shape of a rude flattened letter V.

It must not be assumed that the moraine herein referred to is a mere slender ridge, on the contrary it is a wide, slightly rolling plain, covering the whole or parts of many counties, dotted with grand hills and marked here and there with long kame-like ridges composed of sand, gravel, boulders and clay.

The well at Oxford, in Benton county, which shows a drift depth of 385 feet, is bored where the glacial deposit is probably much thinner than it is along the line of the great ridges described by Professor Gorby in his report of his survey of that county. (See Fifteenth Report). I feel quite sure that there are points in both Benton and Newton counties where the drift, if bored through, would be found at least 100 feet thicker than the table shows. Doubtless the same may be said of Clinton, Boone, Montgomery, Marion, Rush and Randolph counties. It is probable that there are places in Indiana where the drift mass is fully 600 or 700 feet thick, though of course this is mere conjecture based upon the facts at hand. One notable conclusion to which an examination of many sections must lead is that the structure of the drift mass is far from uniform, or in other words, that no arrangement of the elements composing the drift is persistent or continuous over any very large area. True, the same features, or practically the same, appear in all the sections, but the order of arrangement differs greatly. What is blue clay in one bore will be sand in another; if we find gravel here we may find a boulder bed yonder at the same horizon, and a mucky deposit in one well takes the place of hard-pan in another near by. One feature always present, but ever alternating with the other elements of the drift mass, is the boulder clay or till always in massive layers with veins of sand, vegetable muck and soil running through at more or less rare intervals, or with intercellated wedges and lenticular beds of water-bearing gravel compressed within the air tight grasp of its substance. In all the bores where the drift is very thick the sections show a great multiplication of these features. The following drift section of a well at Frankfort, where the deposit was 297 feet thick, will serve as an example of arrangement of the more notable features:

WELL No. 1, FRANKFORT.

Soil and modified drift clay	6 feet.
Grayish-blue boulder clay	6 "
Gravel, with thin streaks of clay	33 "
Hard refractory light-blue clay	22 "
Coarse gravel and water	12 "
Close, semi-plastic drab clay	26 "
So-called "quick-sand" with water rising nearly to surface of bore	44 "
Gray "hard-pan"	61 "
Dry sand, fine and white	20 "
Tough blue clay	20 "
Closely packed gravel bed	47 "
Total thickness	297 feet.

There is some doubt as to whether bed-rock was reached in this bore. The drillers persisted in believing that they struck an immense boulder at the depth of 297 feet, and here the drilling ended. The rock may have been a boulder, if so the drift must have been still thicker; but in Well No. 2, drilled a mile east of No. 1, the stratified rock was reached at a depth of 278 feet, as reported to me by the drillers. It will be noted that at Greenfield, on the eastern limb of the moraine, and at Monticello, on the western limb, the drift depth is identical.

The following table will give a fair general average of the greatest thickness of the drift over that part of Indiana north of the Wabash River, and east of the L., N. A. & C. Railroad line:

TABLE No. 2.

	Depth of drift.
Albion	375 feet.
Elkhart	105 "
Rochester	245 "
South Bend	160 "
Warsaw	248 "
North Manchester	274 "

Indeed, I think it quite certain that the general average of depth throughout the whole area above designated, will be found to be over 200 feet.

In Pulaski and Jasper counties there is a considerable area of very shallow drift, the Niagara limestone coming to the surface, or lying just under the soil, in many places.

In the vicinity of Logansport the nature of the drift mass may be observed to great advantage, and from this point eastwardly and westwardly may be traced another great V-shaped terminal moraine caused by the obstruction offered to the glacier by the northern limit of the Wabash arch. The great dividing ridge between the Wabash and the Tippecanoe rivers northward from Logansport, represents a fair average of this immense formation, which has not yet been sufficiently surveyed to be reported upon, but which may be provisionally assumed to occupy a large part of the area between the Wabash and the Kankakee.

Along the Wabash River the stratified rocks outcrop at Lafayette, Delphi, Logansport, Peru, Wabash, Lagro and Huntington. From Delphi to Huntington the evidences of a marked disturbance of the Niagara limestone can be seen at every exposure, whilst the Devonian strata, whenever present, are non-conformably deposited. At Kokomo, nearly southeast of Logansport and about thirty miles distant, the Niagara rock again crops out, whilst between the two points the drift is very deep.

We may take Marion, Kokomo and Delphi as points in a rudely curving line, defining in a rough way nearly the southern border of the apex of the second great terminal moraine in Indiana. The western limb of this formation appears to coalesce with that of the first moraine in Newton and Jasper counties. I say that this appears to be the case, though as yet the survey of the western division is not far enough advanced to make the statement positive.

The borings through the body of the drift show that water is almost sure to be found imprisoned in the sands and gravels between the masses of blue clay; but there are notable exceptions like that at Frankfort, or that at Lebanon. Indeed, there is no widely general rule discoverable governing the order of drift deposit, the occurrence of water, or the position and thickness of any particular element of the confused, tumbled and jumbled mass. Of course, in circumscribed localities certain features are persistent, to a degree, but are subject to sudden and vexatious changes which may disappoint the well-digger and the geologist as well.

It seems to me that comparatively few of the local and superficial features of the drift ought to be referred to any *forward* movement of the glaciers. Naturally, such of these features as remain unchanged should be expected to show the effects of glacial *retreat*. Sand ridges, if the sand be very light and fine, like shore sand, should be referred in many instances to the action of water and wind, whilst gravel cones and banks may nearly always be explained in connection with either the assorting power of water currents, or the melting of stranded icebergs loaded with the materials. On the other hand, the general and comprehensive features of the drift-mass are the true exponents of the active glacial influence, the forward, aggressive force of the great ice field. The outlines of the vast morainic accumulations are, therefore, the boundaries and the limits of forward plunges of the enormous plow-share which ground up the surface of Canada and flung it down upon the worn and polished rock-beds of Indiana.

The internal structure of the glacial deposit shows, by its alternating clays, sands, gravels and boulder beds, its hermetically sealed pockets of water, gas and vegetable remains, found at all horizons indiscriminately, that in every stage of its formation it was subjected to pressure and relaxation, the erosion of water currents and the sudden obliteration of those currents, the formation of soils and the burial of the same in small basins of blue clay, the huddling of great masses of boulders and the drifting together of all manner of mineral fragments. There is no division line to indicate a separation of epochs. On the contrary, the record is continuous, as sea waves are continuous, billow behind billow with connecting troughs between, from the Ohio River northward to Canada. Indeed, no amount of examination could disclose to the most knowing eye any competent evidence disconnecting one "glacial epoch" from another, or defining the limit or bounding the result of any special, separate ice period, save the one vast, almost unimaginable whole of which the part found in Indiana is comparatively small.

The more I study the drift, the more sections I examine, the more facts I gather, the more I am impressed with the evidence of the immense cycle of time which must have revolved during the changes of temperature which effected in our north temperate zone the transformation of a tropical climate to a boreal one, and then softened the latter in turn to the mild and delightful temperature which now prevails. Some scientists have thought themselves competent to reckon the lapse of years from the testimony of the deposits. These geological almanac-makers are men of high fame and of admirable attainments, but their reckonings as to the limits of past ages are of no more value to geological science than a "*Song of the Arval Brothers*" is to the science of veterinary surgery. No man can give the slightest genuine evidence from which it is possible for him to distinguish between one year and a million years as affecting the period of drift-depositing, or of glacial advance or retreat. He has no data for beginning, middle or ending; there is no starting point which has any known date; there is no monument, not even the slightest trace, by which the halting place may be fixed in time. He may, however, study with good result the constitution of the mass, separate its parts and conjecture with reasonable certainty the points, distant or near, from which these have been transported. But a great deal of patient labor yet remains to be done before even the simpler results can be accomplished with any degree of exactness.

Coming now to that part of this subject which will most interest and benefit the larger body of the people of Indiana, it may be said that the agricultural view of the drift demands an analysis of soils and a study of the subject of proper fertilizers. This will be attended to in the future, if this department shall be authorized and empowered to do so At present there is no laboratory in connection with the State Geologist's office, and no appropriation of funds sufficient to enable the department to prepare for the work of making comparative examinations of soils. It is hoped that the Legislature of the State may soon remove this trouble and give the department a chance to do a great work for the benefit of agriculture in Indiana.

CHAPTER V.

MINERALS AND FOSSILS OF THE DRIFT.

Washings and microscopic examinations of the drift clays, from many sections widely separated from one another, have shown that our "till" bears a great variety of minerals, mostly in a finely comminuted state. Silica, lime and alumina are the chief elements, but aside from these in their most common forms, a great number of mineral substances have been discovered, among the most valuable of which are iron ore and chalk-marl, not to mention the tantalizing traces of gold found here and there associated with a black, so-called magnetic sand. The bowlders and pebbles found in all parts of the mass, represent nearly all the igneous and crystalline rocks of Canada, including many forms of granite, gneiss, schist, quartzite, greenstone and pudding-stone, together with specimens of almost every variety of sedimentary or stratified rock to be found in the area north of Indiana. I have prepared a partial list of the drift minerals and also a table of fossils identified from fragments or from entire specimens found in the drift-clays by me and my assistants. Much may be added to these lists in the future as the survey proceeds.

LIST OF MINERALS FOUND IN THE DRIFT:

Aerolites. (Reported, but not seen.)
Agate. (Usually small fragments.)
Allophane. (In connection with chalk.)
Alumina. (Various silicates.)
Anthracite. (Small fragment near surface, and probably not part of drift.)
Asphalt. (Particles of dry bitumen.)
Beryl (?). (Infinitesimal crystal fragments of pale yellowish green.)
Bitumen.
Bloodstone. (Iron ore, hard hematite.)
Bog iron ore.
Bones. (More or less mineralized, mostly the remains of post-pliocene animals.)
Brown ochre.
Brown ores of iron.
Calcareous tufa.
Calc spar.
Carbon. (See graphite.)
Carnelian. (See agate.)
Chalcedony.
Charcoal.
Chert. (See kaolin.)
China clay. (See kaolin.)
Clay. (Varying from coarse hard-pan, bluish or red, to an unctious white kaolin.)
Claystone.
Coal. (Cannel and ordinary bituminous, in small fragments.)
Copper. (Nuggets of various sizes, thickly coated with green oxides.)
Copperas. (See pyrites.)
Feldspar. (Many varieties.)
Ferrous oxides.
Garnet. (Coarse and dull, small fragments.)
Gas. (Light carburetted hydrogen.)
Gneiss.
Gold. (Mere traces.)
Granite.
Graphite.
Greenstone.
Hematite. (Brown.)
Horn-blende.
Iron ores. (Oxides of many varieties.)
Kaolin. (Not kaolin proper, but a fine white silicate of alumina with lime.)

Laumontite. (Supposed to be, adhering to fragment of copper ore.)
Lead. (Galena.)
Lignite, (Buried wood, more or less transformed.)
Limestone. (Of almost every kind.)
Magnesia. (Various silicates, steatite, serpentine, and the carbonate in magnesian limestones.)
Manganese. (Peroxide)
Marble.
Meteorites. (See ærolites.)
Mica. (In schistose rock-fragments and in fine dust.)
Oils. (Traces of petroleum, etc.)
Opal. (Opalized wood.)
Oxides. (Various.)
Pyrites. (Iron and copper.)
Salt. (Traces.)
Silica. (In many forms.)
Zinc-blende.

It will be seen that the above list, although far from complete, covers a wide range of mineral substances. To the most casual observer it is plain that the material composing the drift is far out of place—that it is all transported matter. The bowlders and pebbles of granite, greenstone, gneiss, trap and schist show beyond question that they have been brought into Indiana from Canada. These fragments are rounded and planed, often finely grooved and striated. The limestone bowlders and pebbles, though not as plentiful as those of the igneus or metamorphic kinds, are found throughout the mass; many of them are fossil-bearing with beautifully polished surfaces showing fantastic sections of the shells and other organic remains.

Below is given a partial list of the fossils found in the drift.

Actinocrinus. (Species not certain.)
Aviculopecten. (Species not certain.)
Bellerophon. (Species not certain.)
Calymene. (Species not certain.)
Chætetes. (Species not certain.)
Chondrites. (Impressions in flat limestone.)
Corals. (Of nearly all the silurian and devonian genera.)
Cardaites. (Species uncertain.)
Orthoceras. (Species uncertain.)
Productus. (Species uncertain)
Pleuratomaria. (Species uncertain.)
Rhynchonella. (Species uncertain)
Streptalasma. (Species uncertain.)

Spirifer. (Species uncertain.)
Tentaculites. (Species uncertain.)
Zygospira. (Probably *modesta.*)

Of course this list might be drawn out to a great length if we should include those fossils found imbedded in the limestone fragments of the drift; but, with the exception of *chondrites*, I have named none save those identified from fragments of the specimens found in the blue clay, and most of these have been very small. As yet this microscopic study of the fossil fragments present in the body of the bowlder till has but fairly been begun. I hope in the future to push it much farther.