THE DRIFT DEPOSITS OF INDIANA.

BY DR. J. S. NEWBERRY.

Over more than three-fourths of the area of the State of Indiana the surface is occupied by a sheet of clay, gravel, sand and bowlders from 20 to 250 feet in thickness, which covers and generally conceals the underlying rocks. These materials have been transported from localities more or less distant north and east, and have been spread by an agent which has been broad and general in its action, and which is now generally conceded to have been ice. It is also believed that this ice was in the form of glaciers, which at different periods attained different dimensions, but which as a whole formed the characteristic feature of a special epoch in geological history; from this cause denominated the Ice Age.

At this time peculiar climatic conditions prevailed over the whole northern hemisphere, the result of a change which brought down to the line of New York, Cincinnati and St. Louis the present average annual temperature of Greenland, and covered nearly all the surface of this continent north of that line with sheets of perpetual snow. The precipitated moisture in that age, borne from the ocean by essentially the same system of rain-bearing winds as now, instead of flowing off through the great channels of drainage by which it is now returned as fast as it falls, accumulated year after year, so that where the precipitation was greatest the snow fields attained the thickness of thousands of feet. As always occurs under such circumstances, the lower strata of the snow fields were compressed to ice, and this ice, though generally regarded as a solid, possessing a peculiar plasticity, flowed downward from the highlands with a slow but constant motion, much as the same substance in its liquid form flows over a water-shed, eroding, transporting and depositing the materials it encounters, but with a broader and more general action.

As we learn from the already ascertained history of the North American continent in former ages, immediately anterior to that interval which we call the Glacial Period, a mild climate prevailed over all its area, even to the Arctic Sea, and the surface was then covered with a vegetation more luxuriant than that of our Middle States, and was inhabited by a fauna containing more genera and species and with animal forms of larger size than those which now occupy any portion of the earth's surface. With the approach of the Ice Period the climate of the shores of the polar ocean became gradually colder, the winters longer and more severe, the accumulation of snow greater and greater, century after century, until Arctic conditions prevailed over all North America east of the Missouri and north of Cincinnati and New York, and over the elevated regions of the Far West, down as far as the northern line of New Mexico. In the advance of this great climatic change the snowfall was greatest on the highlands, and the valleys leading down from these were filled with glaciers which descended as ice rivers along the channels excavated by the previously existing water rivers, broadening and deepening these, and scooping out basins in the bordering plains. As the cold became more intense, these local glaciers coalesced into ice sheets which, with lobed margins, over-rode all local topography, planing down projecting points and filling depressions, reaching far out on to the plain country, until in the maximum of cold the limits I have mentioned were reached. During unnumbered ages a great ice sheet or a series of glaciers, coalescing at their sources, moved down from the Canadian highlands, radially southeast, south and southwest, grinding and scoring the rocks over which they passed, and bringing to its margin—the point where it was melted—the debris of all the rocks it had ground up and dislodged in its passage. This transported material formed a terminal moraine at the extreme limit of the ice field, back of which the rocks were scraped bare and in many instances deeply worn away by the grinding action of sand and gravel under the great weight of the moving ice, and striated by the stones which were frozen into and borne forward by it. Probably the increase of cold was not continuous, but the ice fields advanced with many arrests and retreats, as the seasons suffered annual and secular variation. Finally a permanent amelioration of the climate began, and the glaciers retired to the Far North. In this retreat the terminal moraine, left in concentric and constantly diminishing circles around the glacier edge, formed a sheet of debris that covered, in varying thickness, nearly all of the country the ice had occupied, and thus was formed that great accumulation of drift material which is spread over the plain country south of the Canadian highlands, from Newfoundland to the Mississippi, and thence northward, east of the Missouri, to and beyond the British line. This belt is, in places, 500 miles in width, and, although during the long interval which has elapsed since the Drift sheet was spread, it has been constantly eroded by the wash of falling rains, yet it will perhaps now average over all this area, thirty to forty feet in thickness.

The *marginal line* of the Drift sheet in Indiana has been traced with much care by Prof. G. F. Wright from Ohio to Illinois. This line has been sometimes called the line of the terminal moraine, but it is not true that it is marked by any greater accumulation of transported material than other portions of the Drift area further north. In one sense the whole Drift sheet is a terminal moraine, as it is made up of a collection of contributions of morainic material from the retreating glacier which thus formed a broad sheet by adding concentric lines of contiguous terminal moraines. The margin of the Drift area, as indicated by Prof. Wright, runs from Aurora southwesterly through Ohio and Jefferson counties to Jeffersonville. There it crosses the river and occupies a small portion of Kentucky, as it does opposite Cincinnati. Thence recrossing the Ohio it passes through Clark, Scott, Jackson, Brown and Johnson counties in a northwesterly course to the south line of Morgan county. Here it turns somewhat abruptly and follows a nearly uniform southwesterly course through the counties of Owen, Greene, Knox, Gibson and Posey to New Harmony, where it crosses the Wabash River and enters Illinois. All parts of the State north of this line are covered with Drift deposits, and were once occupied by glaciers. (See Prof. Wright's paper on the *Glacial Boundary in Ohio, Indiana and Kentucky*, page 16, plate 5.)

The *Drift materials* consist, as has been mentioned, of clay, sand, gravel and bowlders. By far the most important of these in thickness and extent is the "till" or bowlder clay, the finer material ground up by the glaciers in their passage over the subjacent rocks, and a characteristic product of glacial erosion in all times and countries. This clay is usually unstratified or irregularly bedded, and is thickly set with smaller or larger fragments of stone, of which the angles are rounded and the sides marked with a peculiar striation, the result of the wear they have received when frozen into the ice and held in contact with hard substances below. From time to time changing their positions in the plastic material in which they were imbedded, different sides were planed and scratched until they have attained the characteristic form and markings by which they are everywhere recognized. Where the bowlder clay was spread over an irregular surface, water-basins were sometimes formed from the melting ice, and here the clay was deposited with no pebbles or bowlders—except an occasional one dropped from the floating ice—and was often very regularly stratified.

This bowlder clay is apparently the debris of the softer materials acted upon by the glaciers, limestones, shales, etc., and the softer metamorphic rocks, clay-slate, mica-schist, etc. The feldspars of granites, where they have been worn away, have also contributed to its formation. It is usually calcareous from the limestones that have lain in the path of the glacier.

The mode of formation of the till, or bowlder clay, has been much discussed in Europe and in this country, and a diversity of views has been expressed in regard to it. By most of the European writers on surface geology, both continental and insular, it is supposed to have been formed beneath the glacier, but in the report on the Drift of Ohio, which forms part of Volume II of the Geology of Ohio, I have given evidence which seems to me conclusive that it was formed at the edge of the glacier by successive contributions made by the retreating and diminishing ice. The planed and scratched surface of the underlying rocks, the sections of fossils, concretions, etc., as well as the fluting of vertical cliffs, prove that the ice was brought into direct contact with the rock, or was separated from it only by a thin layer of sand, which was the cutting agent.

It is impossible that a rock surface should be planed to the smoothness of a house floor, as on the islands in Lake Erie, or grooved and carved with the exactness which many of the ice markings exhibit, by the movement of a mass of gravel, sand and clay pushed forward by the ice. No one can carefully examine the splendid inscriptions made by the ice on Kelley's Islands, Lake Erie, to cite no other examples, without being convinced that during the processes of erosion it was practically in contact with the rock, and that the accumulation of Drift materials above took place at a later date when the ice itself had been withdrawn.

In certain localities we find the stones which were embedded in the bowlder clay crowded together, and with their upper surfaces planed off and striated, forming what are known as *striated pavements.* Here we have proof that the ice sheet, after its retreat, returned and over-rode the moraine it had before formed, and bore it down, much as it had previously done the rocks below. The bowlder clay is remarkably tough and dense, and, where homogeneous, is found to be one of the most difficult materials to remove or excavate. Hence it held the bowlders it contained with great firmness, so that they were quite regularly ground off, without displacement.

In certain localities, however, the returning ice sheet has impinged against the banks of clay it had before piled up, and has with irresistible pressure crushed and crowded them from their former position. These afford examples of what are known as *Contorted Drift*, and such may be seen at various places along the southern border of the lake basins where the great ice mass has been forced against the accumulation of Drift material which covered the southern margins of those basins.

Prof. J. W. Dawson has advanced the theory that the bowlder clay which covers so much of the region about the great lakes was transported and deposited by ice action; suggesting that a depression of the continent at one time permitted the Arctic current which now sweeps the coast to pass into the interior basin, and that icebergs borne by this current not only transported the Drift material, but, dragged over the rock surfaces, produced the planing, furrowing and striation.

I have elsewhere shown, *first*, that the great diversity of level, amounting to over two thousand feet, exhibited by different parts of the margin of the Drift sheet, is incompatible with the theory that this is the water line of a lake or ocean shore; *second*, that the character of the inscription left on the rocks is exactly that of glaciers and not at all such as would be formed by the mere dragging of icebergs over submerged rocks; and *third*, that the Drift of the interior basin nowhere contains any of the marine fossils found in the bowlder clay of the Lower St. Lawrence Valley; which would not be the case if the oceanic current had free access to the interior basin. For these reasons, and particularly for the second, which is, as I conceive, demonstrative and conclusive, I can not subscribe to the iceberg theory.

Prof. N. H. Winchell, who has contributed much valuable and important matter to the literature of the Drift, has suggested that the bowlder clay might have been an accumulation of sand, gravel and bowlders occupying the surface of the glacier, and these, with dust blown from the adjacent land area, were left as a continuous sheet upon the melting away of the ice. That such accumulations might take place on the edge of an ice sheet under certain circumstances is highly probable, but it should be remembered that the stones and dirt which gather on the top of local glaciers, such as are conspicuous features of the glaciers of the Alps, can only occur where the glacier is surrounded by higher land, from which dust might blow and rock masses roll; while the broad glaciers which came down from the Canadian highlands were not overlooked by mountain ranges or pierced by pinnacles of rock from which materials of any kind could reach the surface of the ice, but, so far as we can learn, all the area occupied by the ice sheet east of the Hudson was in the maximum of the glacial period like the interior of Greenland, a shoreless sea of ice.

The *sand* which accompanies the bowlder clay sometimes forms lenticular sheets within its substance, sometimes a layer between the clay and the underlying rock, and oftener surface accumulations washed from the clay in later times. This represents the debris of sandstone worn away, or the quartzose material of granites and other crystalline rocks. Sand seems to have been the most potent grinding agent by which the vast erosion of the glaciers was effected. Lying beneath moving masses of ice hundreds and perhaps thousands of feet in thickness, it was pressed down upon the rocks below with such force as to rapidly cut away all materials exposed to its action. With its aid the glacier became a sort of great emery wheel. The soft ice might break off and carry away ledges of rock that opposed its progress, but was, without aid, incapable of grinding down rock surfaces. When the Drift materials are removed from the underlying rocks their broad planed surfaces, sections made of the fossils, pebbles, bowlders and concretions imbedded in the rock, attest the efficiency of ice and sand as eroding agents; while the modulated surfaces, rounded prominences and monotonous topography of the country once occupied by glaciers, prove the amount of erosion effected by the ice sheets to have been enormous. The weight of a cubic foot of ice is about fifty pounds, so that where the ice was a thousand feet in thickness, and we have evidence from its overtopping mountains that it was over large areas many times that, the pressure of 50,000 pounds or more to the square foot must have made its grinding action rapid and irresistible.

The *bowlders* which form in places a conspicuous element in the Drift are of all sizes, and are composed of very diverse materials. Often they lie buried in the bowlder clay or the associated sands and gravels, but most of those which are seen lie upon the surface. These are sometimes of large size, five or ten feet in diameter, and many have been noticed very much larger. The number of bowlders lying scattered over the surface is probably not an accurate measure of their abundance in the Drift deposits below, for many have been left exposed by the washing away of the softer material in which they were imbedded, but conclusive evidence can be gathered at many points that some of these have been dropped where they are found by floating ice. When, as sometimes happens, these bowlders are seen resting upon laminated and bowlderless clay it is evident that they could not have been transported to such points by the water from which the clay was deposited, as water currents do not carry to the same place fine and coarse material. The finer particles, having a much larger ratio of surface to mass than the larger, are transported to a greater distance and deposited by themselves.

In many parts of the Drift area the glaciers in their retreat were bordered by bodies of water over which fragments of ice of greater or less dimensions detached from the ice mass, as they melted, floating or grounded, released the bowlders or pebbles which were imbedded in them and thus scattered them over the bottom of the basin. Such transportation of greater or smaller rock fragments has been noticed by all who have seen icebergs, and it is well known that these are nothing else than masses detached from the margins of glaciers which have flowed down into bodies of water where the difference in the specific gravity of water and ice has caused fragments of the latter to be lifted up and floated away. In the region now occupied by the Great Lakes, it is well known that the retreating glaciers left water basins, of which the ice formed the northern shore, and from time to time floating ice masses were detached from these which carried to different parts of the water basins fragments of rock taken from the country over which the glaciers moved.

The retreat of the great ice sheet which spread the Drift that covers so much of our Northern and Middle States was not uniform, but was marked by many alternations of retreat and advance, as some seasons and cycles of seasons were colder or warmer than others. Some of these alternations were of long duration and have left distinct and unmistakable records. These are styled *interglacial warm periods*, of which several are specified by European geologists, and at least one great one by those who have studied the Drift phenomena of North America. In a great number of localities we have found two bowlder clays, separated by laminated sand and clay; sometimes by beds of peat, with stumps and trunks of trees, which prove that the surface was for a long interval free from ice and partly covered with a growth of vegetation. In Southern Ohio a bed of peat many feet in thickness is found lying between the lower and upper Drift deposits. In this peat are many trunks and branches of cedar trees, and its surface is covered with a growth of sphagnous moss. There have also been found in it the remains of the giant beaver, which at one time inhabited this country. In many localities not far from this exposure, an old soil with roots and tree trunks has been reached in wells; so that it is evident that here we have proof of a distinct interglacial period, during which the Arctic climate which prevailed before and after was so far ameliorated as to permit the growth over the surface of a vigorous though boreal vegetation. These phenomena I have described in the report on the geological survey of Ohio, and have denominated the sheet of vegetation which is there found in the Drift the *Forest Bed*. Something of the same sort has been noticed in several of the Northern States, including Indiana, and it is evident that this interglacial interval of warmer climate was a distinctly marked epoch in the history of the Ice Period. It should be observed, however, that a part of the accumulation of vegetable matter found beneath the Drift belongs to a time anterior to this, for where "muck beds" and buried timber are met with, as in some places in Indiana, beneath all the Drift deposits, they are probably portions of the old soils and forests that belong to a time anterior to the glacial period, and which in local depressions escaped the denuding action which stripped most of the Drift area of all its superficial material.

The great secular climatic revolution which resulted in the retreat of the glaciers from the fortieth parallel to Greenland was evidently very slow in its progress. Local glaciers in certain localities replaced the great ice sheet, and through ages maintained their flow and did their special work precisely as the local glaciers of the Alps have done in their former extension, and are doing at the present day. In our Western States the retreat of the ice sheet from the plain which bordered the Canadian highlands was accompanied by the formation of a number of local, but still great glaciers, which have left deeply graven and indisputable records of their existence and power. These are the basins of our great lakes, which are broad and deep troughs, for the most part *excavated* in nearly horizontal sedimentary strata. That the lake basins are wholly due to ice action is not claimed; for rivers of ice, like rivers of water, follow the lines of lowest levels, and the surface of our continent was deeply scored by river action long anterior to the Ice Period. As I have elsewhere shown, great rivers traversed the country bordering the Canadian highlands, and received the drainage from this watershed throughout the Tertiary, and probably earlier geological ages.

The valleys of these rivers naturally became the channels through which the glaciers moved when the precipitated moisture held for a time the form of ice, and the effect of glaciers on these river valleys was to expand them into basins such as could not be formed by any flowing stream. All our chain of Great Lakes, as well as those which extend through the Canadian Dominion to the Arctic Sea, hold a similar and significant relation to the Canadian highlands, from which the great ice sheets and local glaciers descended, and it would probably not be difficult to prove that the entire series is chiefly due to the action of local glaciers which existed during the advance and decadence of the Ice Period.

In various papers of which the titles are given below,* I have discussed the origin of lake basins, and it is not necessary here to review the facts, nor in full the conclusions derived from them. Since the last of these papers was written, the subject has been more fully illustrated, and the conclusions reached confirmed in the "Preliminary Paper on the Terminal Moraine of the Second Glacial Epoch," by Prof. T. C. Chamberlin, Washington, 1883, to which I will refer all those who are interested in pursuing it further. Two of the basins of the Great Lakes bear such relations to the area of Indiana that they should be specially mentioned in this connection. Of these one is Lake Michigan, which cuts into the northwestern corner of the State, and of which the great glacier, fully described by Prof. Chamberlin, contributed something to the Drift deposits that occupy its surface. The other basin is that of Lake Erie, which, though not now extending to the confines of this State, was at one time occupied by a glacier, which, flowing from the east in a general way along the line of its major axis, reached and spread a vast amount of transported material over all the northeastern portion of Indiana.

The islands which occupy the west end of Lake Erie are parts of the Cincinnati arch, an axis of elevation running from Canada to Alabama. They are composed of solid limestone, and like the depressed areas which separate them, every where bear marks of ice action, we may even say, have been carved from the solid rock by this agent. Their surfaces are deeply scored by glacial furrows, and their sides in places beaded like cornices. The furrows run nearly east and west, showing that the motion was in this direction, and that it was from the east westward, is proven by the fact that where masses of chert lie in the limestone these are battered on their eastern sides, and toward the west-southwest are joined to long ridges of limestone which have been protected from erosion by them.

*1. Notes on the Surface Geology of the Basin of the Great Lakes, Proc. Boston Soc. Nat. Hist., Vol. IX, 1862.

2. The Surface Geology of the Basin of the Great Lakes and the Valley of the Mississippi, Annals Lyc. Nat. Hist. New York, Vol. IX, 1869.

3. The Origin of the Great Lakes, Geology of Ohio, Vol. II, p. 72.

4. The Geological History of New York Island and Harbor, Pop. Science Monthly, Vol. XIII, 1878.

5. On the Origin and Drainage of the Great Lakes, Proc. Amer. Philos. Soc., Phil., Nov., 1881, p. 91.

SOURCES OF THE DRIFT DEPOSITS.

Probably much of the material forming the Drift sheet in Indiana has been transported no great distance from its place of origin, and the Drift clays may have been largely derived from the erosion of the sedimentary rocks of the northern portion of the State itself, or from the adjacent States and Canada. This fine material presents no characters by which it can be traced to its source, but the pebbles and bowlders with which it is associated are more suggestive. Among these are representatives of a great variety of crystalline and sedimentary rocks which occur in place in localities more or less remote, northwest, north and northeast from the places where they are found. For example, they include:

1. Masses of native copper and greenstone (diabase) from the copper series of Lake Superior, which prove a movement of the ice and transportation of material from points a little west of north and 400 to 500 miles distant.

2. Fragments of granite, slate and iron ore from the iron region back of Marquette, Michigan.

3. Silicified corals and other Niagara fossils from the country lying just north of the head of Lake Michigan or the islands in Lake Huron.

4. Rolled specimens of *Spirifera mucronata*, a Hamilton fossil from the region directly north of Lake Erie.

5. Fragments of the Water Lime and Corniferous Limestone, with characteristic fossils from the islands of Lake Erie.

6. Hudson River Group rocks and fossils from Canada, north of Lake Ontario.

7. Granite and other crystalline rocks from the Canadian highlands north of Lakes Erie and Ontario.

8. Magnetic iron from the Laurentian series north of Lake Ontario and the St. Lawrence (reported).

The identification of these transported fragments may be accepted as proven from all the localities mentioned above, except the last; but it will be necessary to collect, slice and study under the microscope the fragments of crystalline rocks before they can be exactly located in the districts from which they came. It is to be hoped that some one will interest himself in this promising subject of investigation; for the eruptive and crystalline rocks—all of which are foreign to Indiana, and are largely represented in the Drift material—can, without doubt, be traced directly back to their places of origin.

Confirmatory of the evidence furnished by the Drift bowlders, is that of the glacial striæ. If the sheet of bowlder clay could be lifted from the underlying rocks, they would be generally found to be planed and striated in a peculiar manner, and one that can only be attributed to ice action; but most of this inscribed surface is deeply buried, and therefore invisible. Where the Drift has been removed, or never permanently rested, the rock surfaces have been exposed to the action of the weather from the Ice Period to the present time; as a consequence, soft rocks, as shales or limestones, which are dissolved by water holding carbonic acid in solution—as all rain water does—have been removed to some extent, and the inscriptions they once bore obliterated.

Hence, it is only in a few localities that natural exposures still retain the glacial markings; and it is not, perhaps, surprising that for lack of this evidence the former presence of glaciers in Indiana has been denied, and the spread of the Drift material has been referred to flowing water or iceberg transportation. It fortunately happens, however, that a great number of railroad cuts, cellars, wells, and pits of various kinds have been sunk through the Drift to the rock, and these, in a thousand localities, have shown that the rock surfaces which have been protected from weathering by sand and clay still bear the undeniable and distinctly legible autograph of the glacier. Hence, abundant proof can be offered to the doubting that up to the margin of the Drift area, ice has moved in solid sheets from some northern region. By comparing the bearing of the scratches and furrows which it has left in its passage, we also learn that at one time or another streams of ice have flowed from all of the points to which we have traced the transported bowlders. Thus an unbroken chain of evidence proves that the Drift material, now scattered over so much of the surface of Indiana, has come from all this wide northerly region, and that the transporting agent has been for the most part glaciers, and not icebergs, although in the eventful history of the Ice Period icebergs took an important though local and subordinate part.

CAUSES OF THE COLD OF THE ICE PERIOD.

The evidences of the former extension of glaciers into low latitudes have been found not only across North America, but in different parts of Europe and Asia, and similar phenomena to those which constitute our record of an Ice Age, have been detected in various parts of the Southern Hemisphere—Patagonia, Chili, New Zealand and Australia. All these have excited much interest, and many theories have been advanced to account for the former spread of Arctic conditions over the enormous area where they temporarily prevailed. The first and simplest explanation was that given by Lyell, who, with characteristic conservatism, explained the former extension of snow fields and glaciers by supposing that a peculiar topographical condition prevailed in the Northern Hemisphere during the Glacial Epoch. According to his view, the land of the Arctic region was high and continuous at that time, and the ocean currents which now penetrate and warm the Arctic seas, were then excluded by land barriers. In that case, the heat of the tropics would be confined to the tropics, where it would result in evaporating vast quantities of water, which would be precipitated on the great condensers of the Arctic highlands. But geology shows us that the Arctic highlands were high and broad *in the Tertiary*, and that barriers did then shut the tropical currents out of the Arctic ocean; yet the temperature was in all that region much higher than now. On the contrary, in the Ice Period the northern land was apparently low, as the Champlain clays, which are composed of the fine material ground up by glaciers, were deposited by sea water over a great area in the north which is now land. Beginning at New York with the sea level, they reach an altitude of 200 feet at Albany, 350 in the Champlain valley, 500 in the St. Lawrence valley, 800 in Labrador, 1,000 in Davis' Straits, and 1,500 to 1,800 on the coast of Greenland; and these clays contain Arctic shells and were plainly laid down by the sea during the Glacial Epoch.

Whatever theory is offered to account for the Ice Period must equally apply to the Southern Hemisphere. But it is evident that no barrier of land in recent Geological times connected Cape of Good Hope with Cape Horn and the East Indian Archipelego. Therefore the Lyellian hypothesis, however simple, can not be accepted.

Col. Drayson, the author of *The Last Glacial Epoch*, advocates the view that the angle of inclination of the earth's axis with the ecliptic—which is now constantly changing within narrow limits—was in former times far more variable, and that the North Pole has occupied many different places, giving to each in succession an Arctic climate. Astronomers are generally agreed, however, in rejecting this theory, regarding it as a mere conjecture, sustained by no facts and opposed to all that is known of the mechanism of the solar system.

Without discussing further all the suggestions that have been made in regard to terrestrial causes of the climate of the Ice Period, it may be said that none has yet been offered which has any considerable claim to confidence, and we are almost driven to look to some extraneous and astronomical cause for an explanation of the phenomena. Three theories have been offered which suppose the earth to have been affected by external influences which have at times greatly modified its climate. Of these one supposes the earth to have passed through cold places in the stellar universe, and another that the heat of the sun, which now determines the surface temperature of the globe, has been variable, at times greater and at others less than at present. But no warrant is given for either theory by any observed facts, and the burden of proof lies entirely with their proposers.

Finally, a theory was brought forward by Prof. Croll, of Glasgow, which at once secured a large amount of favor, and at present is very generally accepted as the most plausible of any yet suggested. This theory is that the variations in the eccentricity of the earth's orbit, which have been carefully calculated for millions of years, forward and back, and shown to have been at times far greater than now, have, in combination with the precession of the equinoxes, caused secular changes in the climate of the Northern and Southern Hemispheres alternately, as great as any which geology reports. In his interesting work, *Climate and Time*, Prof. Croll elaborates his theory at great length, and proves, first, the reality of great variation, and second, its adequacy to account for a share, at least, of the climatic changes recorded.

These propositions can not be denied, but there is some difference of opinion as to the manner and measure of the changes of climate which would result from a great variation in the eccentricity of the earth's orbit. Probably there will never be perfect unity of sentiment in reference to this point, but Prof. Croll deserves the gratitude of the scientific world for suggesting what must have been the cause of marked, and probably great, climatic revolutions.

THE ICE PERIOD A COLD PERIOD.

As ice is a condition of water produced by cold, and glaciers and snow fields are confined to cold portions of the earth's surface, the natural inference from the evidence of the former great extension of glaciers is that they were simply the product of a depression of temperature; but as no accumulation of ice and snow could take place without the precipitation of moisture and the previous evaporation of that moisture in some other locality, it is true that the formation of snow fields and glaciers will be to a certain extent measured by evaporation and precipitation. Hence, several writers upon the Ice Age have taken the view that its characteristics were due rather to an increased evaporation and precipitation than to an increase of cold.

For example, one very distinguished scientist has suggested that in the Ice Period great volcanic eruptions in the tropics threw into the air vast quantities of moisture, which was precipitated as snow and formed ice in all elevated regions, north and south, and thus produced the great snow fields and glaciers, of the existence of which we have such abundant evidence. But there are difficulties in the way of this theory which are quite insurmountable:

1. We have no indications in the tropics of any extraordinary volcanic outbursts, and we may be quite sure that any of such magnitude as to materially affect the precipitation of moisture in the Northern and Southern Hemispheres would have left an unmistakable record. It should be remembered that the evidences of ancient glaciation extend quite around the earth in both Hemispheres, and, even if it were true that volcanic eruptions, like that of Krakatoa, would load the atmosphere with an abnormal quantity of moisture, it would be necessary to have a ring of

such volcanoes quite around the central zone of the earth to produce the general precipitation which this theory requires; and also that the volcanic action should be continued through many thousand years in order that the glaciers might produce the immense erosion, transportation and deposition they effected.

2. It may well be doubted whether the conversion of water into steam in the tropics, on however grand a scale, would result in any great increase of the precipitation in the Arctic regions, since most of the evaporated moisture would rise directly to an altitude where the temperature is so low that it would be condensed and sent back again to the earth in deluges of rain, and the small surplus, if any there were, would, according to the system of atmospheric circulation which now prevails, descend to the surface before reaching the Tropics of Capricorn and Cancer.

A vast amount of moisture is evaporated under the equator at the present time, and yet this is so generally precipitated within the tropics that, as Prof. Loomis has shown, the zone where the air flowing from the equator toward the poles reaches the surface is a zone of special dryness.

3. No increase of annual precipitation would result in rebuilding the glaciers which occupied low latitudes in the Ice Period. For example, the present rainfall on the mountains of Oregon is quite heavy, and the snow accumulates there to the depth of many feet in winter, but in summer this all melts away, except upon certain elevated summits where perpetual snow is by its mere quantity carried down to a level where there is a vigorous forest growth. It is easy to see that an increase of rainfall, however great, on the Cascade Mountains, would never form glaciers without a depression of temperature; but the rainfall continuing the same as now, if the winter temperature of that region could be maintained through the year, glaciers would certainly be formed and spread over the great area they occupied during the Ice Period.

In the same way an increase of rainfall over the drainage basin of the St. Lawrence, a region once covered with glaciers, would never restore the ancient conditions without a depression of the annual temperature. If, however, the cold of the Canadian winter could be continued throughout the year, not many centuries would elapse before the Canadian highlands and all the bordering plain would be covered with ice sheets. Hence, we are forced to the conclusion that the Ice Age was attended with a depression of temperature simultaneously or alternately in the Northern and Southern Hemispheres, and that this depression of temperature, due to some extraneous and not terrestial cause, produced the distinguishing characteristics of the Age.

TABLE OF ALTITUDES OF CHICAGO & INDIANAPOLIS AIR LINE R. R.

BY DR. H. MOORE.

STATIONS.	Distance from Indianapolis.	Elevation Above Ocean.
Indianapolis Union Depot	....	721
Junction	....	762
Broad Ripple depot	8	755
White River rail	8.2	759
Hamilton and Marion county line	12	836
Carmel depot	16	860
Westfield depot	20	935
Hortonville depot	24	945
Sheridan depot	28	980
Sheridan, west corp. line	28.6	998
Boone and Hamilton county line	29	993
Terhune depot	32	994
Clinton and Boone county line	34.5	970
Kirklin depot	37	956
Sugar Creek bed	38	917
Cyclone depot	41	962
Frankfort depot	47	893
South Fork Wild Cat rail	49.5	855
South Fork Wild Cat bed	....	825
Rossville depot	58	740
Middle Fork Wild Cat rail	59	740
Middle Fork Wild Cat bed	....	720
Carroll and Clinton county line	59.2	740
North Fork Wild Cat rail	62	717
North Fork Wild Cat bed	....	659
Radnor depot	66	725
Deer Creek rail	72	717
Deer Creek bed	....	645
Delphi & Wabash R. R	....	689
Wabash River rail	....	650
Wabash River dam below Pittsburg	74	626
Highest point between Wabash and Tippecanoe Rivers	....	683
Tippecanoe River below dam	84	593
Monticello depot	85	675
Monon depot	95	674
Lee depot	100	685
Marlboro depot	105	674
Pleasant Ridge	107	695
Iroquois River bed	110	660
Rensselaer depot	111	670
Surry depot	116	716
Fair Oaks depot	121	697
Rose Lawn depot	128	667
Thayer depot	130	682
Kankakee River	131	670
Lowell	139	700
Creston	142	750
Cedar Lake water summit	144	730
St. John's depot	150	707
Dyer depot	155	640
Hammond	163	....
Lake Michigan water summit	....	585