THE ICE AGE IN NORTH AMERICA.

Lectures before the Lowell Institute, Boston, 1887.
By G. Frederick Wright.

I.

SYLLABUS.

INTRODUCTION. SIGNS OF GLACIAL ACTION. EXTENT AND DEPTH OF THE CONTINENTAL ICE-SHEET.

1. INTRODUCTION.—Grandeur of the glacial theory. Pre-eminence of the North American field. Summary of facts concerning existing and former glaciers in other parts of the world; those radiating from the Scandinavian centre. Recent discoveries by Professor Lewis in England. Relation of icebergs to existing glaciers. Observations of Captain Cook. Facts collected by the Board of Trade in England. Former extent of the Alpine glaciers.

2. General survey of the glaciated region in North America.

3. Signs of glaciation. The known nature of ice upon which inferences can be based. The action of water and ice differentiated: (1) Glacial groovings and scratches; (2) Immediate glacial deposits unstratified; (3) The contour of the glacial boundary is both serrate and crenate: the hypothesis of floating ice eliminated: (*a*) By the fact that there are no barriers at the south to limit the extension of the so-called glacial deposit; (*b*) By the fact that in the same latitude and in adjoining localities the southern boundary of the glacial deposits forms an approximately straight line over hills and valleys.

4. The depth of the ice: direct proof that it was a mile deep in New England and more than half a mile in the Mohawk valley; indirect proof that it was equally deep all over the region of the Great Lakes. Difficulty of mathematical calculations. The viscosity of ice undetermined. Observations upon its movement in great masses give unexpected results.

CONCLUSION.

The study of the glacial period in North America invites our attention for a variety of reasons:

1. It brings before the mind's eye a most flexible and majestic geological force in the height of its activity. Great as is the extension at the present time of the polar ice over the little known Antarctic continent, and vast as is the field over which the glacial forces in past time operated in Europe, these displays of ice-action dwindle into comparative insignificance when set alongside the extension of glacial ice during the height of the period in North America. During this age it was one continuous ice-sheet from

the North Pole to latitude 38° in Southern Illinois, a distance of more than 3,600 miles; but the Scandinavian glacier never extended as far south as the 50th degree of latitude. The width of the great ice-sheet in North America along the northern boundary of the United States was scarcely less than 5,000 miles, extending from the 50th meridian to the 130th.

2. The study of the subject is also of special interest because of the ease with which it can be conducted. Over the whole of British America and the northern part of the United States the marks of the glacial period are everywhere visible. The active forces of that far-distant period still speak to us in the terraces of every river valley, in the granitic boulders that dot the fertile agricultural regions, in the vast piles of debris which constitute the terminal moraines, in every railroad-cutting and river bank which exposes the unassorted material of the vast ground moraine, and in the innumerable scratchings and groovings which are revealed almost everywhere upon the northern slopes of recently uncovered rocky surfaces.

3. The subject is of interest, also, because of its practical character. It will be seen that the chief centre of the agricultural, industrial, political, and moral forces which are to determine the future of this continent is within the glaciated region, and that it is not there by accident, but by virtue of the beneficent activity of the great North American ice-sheet. Alike the fertile prairies of the Mississippi valley, the extensive wheat-fields of the Red River region, the highways to the interior opened up by the Great Lakes, and the innumerable waterfalls which have given the Northern States their pre-eminence in manufacturing industries, are all the direct heritage of the glacial period.

4. The study of the glacial deposits is likewise necessary to the protection of the health and safety of the population dwelling within the glaciated area. No man can properly dig a well, or buy a farm, or choose a place of residence where drainage and freedom from malaria are of first importance, or spend his money in boring for gas or oil, or trust his life in a coal-mine, without paying tribute to the science of glaciology.

5. Nor, finally, should we omit to mention the interest attaching to this subject from its relation to the antiquity of man, since there can be little doubt that man appeared in the world before the close of the ice age. Therefore the study of the glacial period passes out of the field of geology into that of history, and the archaeologist and historian must henceforth seriously reckon with the glacialist.

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II.

SYLLABUS.

Glacial Erosion and Transportation.

1. Erosive action of ice compared with that of running water; water has acted through a longer time. Enumeration of river gorges. Chemical action of water.

2. Intensity of the erosive action of ice. Methods by which earthy material is incorporated into and transported by a glacier. Formation of lateral, medial, and terminal moraines. The action of a glacier on the bottom, not like a plough, but like a drag. The ground moraine as solid as the ice itself. The erosion less intense near the margin of the glacier; greatest in its central portions.

3. More detailed statement of facts. The size of boulders. The distance to which and direction in which boulders have been transported; Plymouth Rock; Judge's Cave near New Haven; trains of boulders in Richmond, Mass.; boulders in Northern New Jersey; upon the summits of the Appalachians in Northern Pennsylvania; in Southern Ohio; in Northern Kentucky; in Southern Indiana and Illinois. The tendency of boulders to rise in the ice.

4. Retreat of the forests before the advancing ice-sheet.

5. Transportation by subglacial streams; estimates of the extent of this in Switzerland; from the Jakobshavn glacier in Greenland; from the Muir glacier in Alaska.

6. Depth of the glacial deposits over New England, Pennsylvania, and Ohio. Proofs that these deposits are chiefly of mechanical origin.

7. Attempts to measure glacial erosion directly: by Professor Shaler in New England; Professor Lewis in Pennsylvania; Professor Newberry and myself in Northwestern Ohio. The complications of the question.

Conclusion.

1. Like everything else connected with the action of such a complicated cause as that brought into view in the production of glacial phenomena, the exact extent of its erosive and transporting power is difficult to determine. The action of ice over the glaciated region took place after other forces had been in full operation during long ages; and hence it is difficult to separate the effects of the second cause from those of the first.

2. There can be no doubt that running water is by far the most efficient of all eroding agencies which have given shape to the contour of the continents. Water acts both as a solvent and as a mechanical agency. Extensive regions have been undermined and lowered through the removal by water of the soluble salts. Such has perhaps been the origin of many of the valleys of the Appalachian region and of some of the great lakes of the world. Running water is also a most effective mechanical agency, continually acting along the natural lines of drainage. The sand and gravel rolled along over the bottom of a rapid stream of water act like a rasp or a saw, and have everywhere worn deep narrow channels across the slowly rising mountain chains. Water as an eroding agency has had a great advantage over ice in the far greater length of time during which it has been in the field to operate.

3. Still, ice has had no small part in transforming the appearance of the portions of the world to which it has had access. Of this the evidence is abundant in the great number and size of the boulders scattered over the glaciated region. Boulders hundreds of miles from their native ledges and weighing hundreds and even thousands of tons are frequently encountered.

4. But as ice is only frozen water, its melting torrents aid in the transportation. The finely comminuted material ground up underneath the ice is largely carried away by the torrential subglacial streams continually pouring out from the ice-front. It is doubtful if the larger part of the glacial grist is not thus transported far beyond the limit of the glaciated region.

5. Still, the extent of the glacial deposits yet remaining over the southern portion of the glaciated region is immense. Probably not less than 1,000,000 square miles of territory in North America is covered with an average depth of fifty feet of glacial debris, forming the most permanently productive portion of the continent. It is in the extent of these glacial deposits, and in the certainly great amount of transportation by subglacial streams, that we have our most certain and impressive evidence of the enormous erosive activity during the glacial age.

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III.

SYLLABUS.

The Terminal Moraines.

1. The confluent character of the great ice-sheet. The unglaciated area of Wisconsin. Moraines of retrocession.

2. Factors determining the amount of terminal deposits. Extent to which the moraines have been removed by erosive agencies.

3. Detailed account. The moraine in the Gulf of Maine; south of New England; on Long Island; in New Jersey and Eastern Pennsylvania. Characteristics of this part. Kettle-holes; their formation illustrated. The moraine independent of local contours of elevations. Its characteristics in Western Pennsylvania; in Ohio, Indiana, Illinois, Dakota, and British Columbia.

4. Moraines of retrocession. The "Kettle Range" of Wisconsin and the Northwest; moraines between the Wabash and Maumee rivers in Ohio. The lobate character of the retreating ice-margin. The question of successive glacial periods.

5. The lenticular hills of New England and New York; their structure, distribution, and probable origin. Local moraines in the White, Rocky, and Cascade mountains.

CONCLUSION.

1. The ice age of North America doubtless began in local glaciers which subsequently became confluent over the whole glaciated area; and it is evident that the currents of ice-movement at all times felt the direct influence of these local subcentres. An extensive region in Southwestern Wisconsin was never covered by ice, though the glaciers became confluent south of it and extended onwards a distance of two hundred miles. The effect of these subcentres of glacial radiation is to be seen in the lobate character of the terminal moraine, which naturally was more marked during the intermediate stages both of the advance and the retreat than at the time of maximum extension.

2. The term terminal moraine is somewhat misleading, since the amount of terminal deposit is likely to vary so much in amount in different places. Where the ice is for a long time stationary, and in front of regions where the rocks are more easily disintegrated or more accessible to the ice-streams than elsewhere, it is evident that unusually large terminal deposits will take place;

while, over regions where the ice both advanced and retreated regularly, the deposits would be more equably spread over a wide margin of terminal frontage. This probably accounts for the lack of great ridges of terminal deposits in the interior States such as are to be found in Southern New England. The total amount of deposit is as great in the interior as near the coast, but it is spread over a wider area.

3. The "kettle moraines" of Wisconsin and the Northwest are capable of two diverse interpretations. By Professor Chamberlin and others they are taken as moraines of a second glacial epoch during which the ice extended no farther south in that region. For myself I am not convinced that the evidence for a complete separation of glacial epochs is made out in this country, whatever may have been true in Europe.

4. But at any rate the separate lines of terminal moraines, and, as I believe, the lenticular hills of New England, which are specially abundant about Boston, indicate that there were great irregularities both in the advance and in the retreat of the ice during the glacial period. From a combination of causes which cannot yet be explained there were periods of rapid advance and retreat of the ice, intercalated with long periods of established equilibrium. The glacialist possesses the great advantage of having a most complicated cause at hand to account for his phenomena. But while this enables him to account for everything, it as well prevents him from being overconfident in any special solution he may present of minute problems.

5. In the study of the moraines, lenticular hills, and ground deposits of the great ice age in North America we have abundant testimony that the earthy material underneath the ice moved somewhat after the law of the ice itself, and was not shoved along as by an irresistible pushing force. It was rather *dragged* along, and the whole movement towards the margin was after the analogy of the movement of the breakers on the shelving shore. The formation of icebergs, at the present time, wherever glaciers come down to the sea, illustrates this movement. The ice is pushed over into the water from the top, leaving the channel in front of the glacier clear of ice to the bottom. In July last the captain of the steamer in Glacier Bay, sounded from the bow of his boat within twenty feet of the front of the Muir glacier and found more than 106 fathoms of water, thus proving that the face is perpendicular down to the bottom.

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IV.

SYLLABUS.

Glacial Drainage.

1. Post-glacial time much shorter than preglacial time. Extent of preglacial erosion, enormous. The sedimentary rocks, all the result of erosion and deposition. The effects of preglacial erosion seen everywhere outside the glaciated region. The Ohio, an example of preglacial erosion. The length and depth of its trough. Other examples in the Hudson, the Mohawk, the Susquehanna and the Mississippi rivers. The preglacial drainage of the Great Lakes.

2. The ice itself, as a temporary barrier, changing the lines of drainage. The Mississippi River during the glacial period. The Minnesota River and its connection with the Red River of the North.

3. The relation of terraces to the floods at the close of the glacial period. Terraces confined to rivers rising in the glaciated region. Extent and universality of terraces within the glaciated region. Particulars concerning the terraces at the junction of Beaver Creek and the Ohio River, in Pennsylvania. Conspicuous absence of terraces from certain other streams.

4. Kames: (1) definition; (2) description. Comparison between kames and terminal moraines. Kettle-holes common to both. The manner in which kames are formed. Particulars of the kame-systems of New England. The connection between kames and the sandy plains of the glaciated region. Kames, to a certain extent, independent of the minor irregularities of the regions in which they are found. Instances in which they slope toward the ice-front; Lewis's explanation of these facts on the theory of backward drainage.

5. Temporary line of drainage from the Connecticut to the Merrimack valley, in Grafton, N. H. Mr. Upham's explanation. Remarkable effect of the ice-barrier in temporarily diverting the drainage from the James River in Dakota to the Missouri River.

Conclusion.

1. The extreme length of preglacial as compared with post-glacial time is evident from the enormous extent of preglacial erosion. Outside the glaciated region all the rivers occupy deeply eroded valleys, showing the great length of the time through

which the eroding agencies have been at work. The post-glacial gorge of Niagara is but seven miles long, whereas the preglacial gorge of Ohio is both wider and deeper than that, and is more than a thousand miles long.

2. It is easy to see that all the northerly flowing streams of preglacial drainage would be dammed up by ice during the greater part of the glacial period. Of this as a reality there is abundant evidence. All the streams which rise within the glaciated region and flow to the southward were compelled to carry away not only the annual precipitation, but, during the closing stages of the period, they were gorged with the waters of the accumulated precipitation of many thousands of years. If the annual spring freshets of these streams are oftentimes terrific, what must have been the spring freshets in the glacial period itself?

3. Into the Mississippi also were poured in addition the surplus waters which now flow down the St. Lawrence, and into Hudson's Bay. Lake Erie emptied its waters through the Wabash River, and Lake Michigan down the Illinois; while the great region drained by the Red and other rivers of Manitoba and British Columbia had their outlet through Lake Traverse and Big Stone Lake, into the Minnesota, and thence into the lower Mississippi. The terraces of the glaciated region are the direct results of these glacial floods, and can be studied on every stream within the glaciated area.

4. Besides the glacial terraces of our present streams, we have in the so-called "kame systems" still further evidence of the existence of temporary lines of drainage determined by ice-barriers during the continuance of the glacial period. New England is gridironed by a system of gravel ridges deposited by glacial streams to a great extent independent of the minor features in the present topography. In these and in the terminal moraines we study the skeleton of the continental ice-sheet as intelligently as the anatomist can study the skeleton of a dissected animal.

December 2.

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V.

SYLLABUS.

GLACIAL DAMS, GLACIAL LAKES, AND GLACIAL WATERFALLS.

1. The two varieties of glacial dams: (1st) Those produced by irregular deposits of moraine material. (2d) Those consisting of barriers presented by the ice itself. The first class, subdivided into (*a*) Deposits closing up old watercourses; (*b*) Enclosures of the nature of kettle-holes.

2. Number and variety of basins of the kettle-hole type; peat-bogs of New England and Ireland; small lakes of Plymouth county, Mass.; chains of lakes marking kames and moraines; the system of small lakes in Wisconsin, Minnesota, and Dakota, foreseen by Mr. Upham in advance of observation.

3. Obstruction of preglacial channels by glacial deposits and the production of waterfalls. Absence of waterfalls in the unglaciated region; their frequency and the shortness of the gorges below them in the glaciated region.

4. Lakes produced by permanent glacial dams: (1) Winnipiseogee; (2) Chautauqua and other smaller lakes of New York; (3) Lake Erie.

5. Lakes caused by ice-dams during the recession of the ice-sheet. The parallel roads of Glen Roy. Post-glacial beaches around lakes Ontario and Erie. These, the results of an ice-barrier across the valley of the Mohawk and of the St. Lawrence. Lake Agassiz and the great wheat region of the Northwest.

6. The glacial dam in the Ohio at Cincinnati: first discovery of evidence concerning it; supposed height and effects of it; supposed confirmation of its existence found by Professor White in the terraces of the Monongahela and other tributaries of the upper Ohio; measure of uncertainty in such evidence.

7. Crucial facts supporting the theory: (*a*) Lack of terraces in Baker's Fork of Brush Creek, Pike county, O.; (*b*) Granitic pebbles at the head of Chartiers Creek, Washington, Pa.; (*c*) High-level terrace of glacial material at Bellevue, on the Ohio River, near Pittsburgh; (*d*) Freshness of the vegetable deposits in the 1000-foot terrace in the upper Monongahela, near Morgantown, W. Va.; (*e*) Teazes valley, in Putnam county, W. Va.; (*f*) Freshness of the high terraces on the Big Sandy River and their conformity in height with that of the supposed dam.

CONCLUSION.

1. The effect of the permanent changes produced by the moraine deposits of the glacial period are multifarious and beneficial in the extreme. To permanent glacial dams we are indebted for nearly all the waterfalls which add so much beauty to the natural scenery, and furnish power for so many manufacturing industries. The grandeur of Niagara is not diminished by the fact that Lake Erie is a glacial mill-pond. The lakes of New England, Central New York, and of Wisconsin, Minnesota, and Dakota lose none of their charm to the scientific man because they are now known to be nothing but glacial "kettle-holes." It is rather the case that the lakes of strange name in the State of Maine, together with the much-frequented shores of Winnipiseogee, Chautauqua, and Minnetonka, should have an added interest, since we know how they were made.

2. Much interest is added, also, to the Great Lakes, now that we understand the significance of the sandy and gravelly ridges which surround them at levels of from one hundred to two hundred feet above their present surfaces. With the mind's eye the glacialist sees in these lake ridges indubitable evidence of a former vast expanse of water twice as large as that now occupied by lakes Erie and Ontario, and held up to the level of the low places in the water-parting between it and the Ohio, by a lingering mass of ice sent down from the subglacial centre of the Adirondacks to obstruct for a time the valley of the Mohawk.

3. Likewise the glacialist travelling over the great wheat region of the Northwest, with the mind's eye sees, even from the car windows, the restless waves of Lake Agassiz held in place by the slowly retreating ice-barrier to the north, and covering an expanse of territory larger than the largest of the present Great Lakes. The inhabitants of that region have abundant reason to bless the kind Providence which ordered the movements of the glacial period.

4. Of less practical advantage, but of even more theoretical interest is the study of the supposed ice-dam at Cincinnati. The Ohio is still the most remarkable of all the rivers of the world for the extent and suddenness of its fluctuations in volume; at one time being so shallow that in places a child can ford it, while at other times it is a raging flood, a mile in width and seventy feet in depth. But during the time when the ice of the glacial period reached its most southern point of extension, the Ohio above Cincinnati was a slack-water stream 600 feet in depth, so that a ship could sail 300 feet above the site of Pittsburgh.

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VI.

SYLLABUS.

THE CAUSE OF THE GLACIAL PERIOD.

1. The combination of favorable conditions necessary for the production of a glacier.

2. Discussion of cosmical theories: (1) Shifting of the earth's axis; (2) Changes in the temperature of the sun; (3) Precession of the equinoxes and the varying excentricity of the earth's orbit (Mr. Croll's theory); (4) Other theories.

3. Objections to Mr. Croll's theory: (1) These changes do not affect the absolute amount of heat received during each year; (2) The distribution of heat over the earth is little understood; (3) Ignorance of the diathermancy of the atmosphere; (4) Statistics concerning the relative temperatures on the equator and in the high latitudes disprove Croll's calculation; (5) Imperfect knowledge of aerial currents.

4. Adequate theoretical causes for the glacial period are abundant. Slight permanent changes which might increase the size of present glaciers. Delicacy of the equilibrium of meteorological forces.

5. The cause of the lobate character of the glacial boundary in North America is not to be found in isothermal lines, nor in differences of elevation, but in the existence of special centres of excessive precipitation to the north.

6. Glacial theory presents a hopeful field of investigation to the mathematician and the meteorologist.

CONCLUSION.

1. Geology is pre-eminently a terrestrial science, and there is danger of a misdirection of effort when the geologist forms an alliance with the astronomer.

Astronomical data are so largely theoretical, and the quantities which the astronomer multiplies are often so nearly infinitesimal that quantitative error is in peculiar danger of becoming enormous in large calculations. Hence we cannot count it altogether an advantage that astronomical speculation has been so rife during the past few years in determining the causes and the chronology of the glacial period.

2. Of the various cosmical theories to account for the glacial period that of Mr. Croll is by far the most plausible and interest-

ing. It must be admitted that his data concerning the various distances at which the earth is found from the sun during the winters of different periods, and concerning the periodical variations in the length of the winters, rest upon well-ascertained facts. It is no doubt true that about 100,000 years ago the winters were several days longer than now, and the northern hemisphere was receiving daily considerable less heat than now, since it was several millions of miles farther away from the sun.

3. But the distribution of the earth's heat by winds and oceanic currents is a subject concerning which much less is known. The phenomena presented in a hothouse are puzzling. The heat of the sun goes through the glass, but cannot readily get out again. It is well known, also, that a slight increase of moisture in the atmosphere, or a slight film of cloud over the sky prevents a frost. The real problem lies, therefore, in the meteorological field. Now, during Mr. Croll's "aphelion" winters, the summers are in "perihelion" and the summer heat in this hemisphere while in perihelion is more intense than at other times. In fact, the earth receives at all times the same absolute amount of heat from year to year. Thus we cannot avoid the conclusion that the predominant influence in climate consists in the power of moisture-laden atmosphere to retain and transport the heat, thus determining its distribution. As a matter of fact we find that the equator is not so hot as theoretically it should be, and the Arctic regi ns are by no means so cold as they ought to be on Croll's theory. The difference between the mean temperature on the equator and that at the coldest point on the 67th parallel, is, really only about 75° F.; whereas, if the temperature at these points were proportionate to the amount of heat received from the sun, the difference would be 172°. Such facts as these lead meteorologists to regard Mr. Croll's theory with much less favor than formerly.

5. But the glacialist is not so much concerned to know the ultimate cause of the glacial period as he is to collect the facts which characterize the period. The truth is that the meteorological forces of nature are so powerful and complex that there is an embarrassment of riches in the field of glacial theory. It is easy to see that a slight increase of snowfall over the Alps would cause a permanent enlargement of all the glaciers of Switzerland, and threaten every interest of that republic, and indeed perhaps of Central Europe; for the ultimate effects of a climatic disturbance in one such centre cannot well be estimated.

6. Much light upon the condition of things during the glacial period in America must yet come from a careful study of the lobate contour of the terminal moraines. The shapes of these moraines, coupled with what may yet be learned concerning the nature of ice and concerning the shifting course of the atmospheric currents, will, in all probability, eventually furnish the data for the solution of the question of the true cause of the glacial period. A fair field here invites the active and prolonged attention of some future meteorological Darwin or Newton, and promises immortality such as they have attained.

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VII.

SYLLABUS.

The Date of the Glacial Period.

1. Recent undue reliance upon theoretical considerations: Croll's theory an unsafe guide; Lyell's principle of uniformity misleading; tendency to diminish the estimates of geological time; Darwinism interested in shortening glacial chronology; importance of collecting terrestrial evidence.

2. Man in America before the close of the glacial period: (1) Dr. Abbott's discoveries in Trenton, N. J.; (2) Similar and recent discoveries in Southern Ohio; (3) My own investigations as to the age of the gravel deposits in New Jersey and Ohio; (4) Relation of subsequent discoveries to those investigations.

3. Sources from which light may be expected upon glacial chronology: (1) Amount of subsequent erosion: (*a*) In the Niagara River; (*b*) In the Mississippi River below Minneapolis; (*c*) Streams in Northern Ohio; (*d*) Post-glacial gorge in Paint Creek, Ross county, O.; (*e*) In the valley of Raccoon Creek, Granville, O.; (*f*) Plum Creek, Oberlin; (2) The degree of integrity and freshness characterizing the kames and moraines of the glacial period; (3) The limited extent to which glacial lakes and kettle-holes have been filled with sediment: (*a*) Lake Michigan; (*b*) Pomp's Pond, Andover, Mass.; (4) Freshness of organic remains in glacial deposits: (*a*) In Southern Ohio; (*b*) In Central and Southern Indiana; (*c*) In terraces in Western Virginia contemporaneous with the Cincinnati ice-dam.

Conclusion.

1. The historical pertinency and importance of glacial investigation need no further vindication. For many years it has been known that man was in Europe before the close of the glacial period. As early as 1873 Dr. C. C. Abbott began to discover paleolitic implements in the gravel deposits near his home, on the Delaware River, in Trenton, N. J. Similar discoveries have also been made by Miss Babbitt in Minnesota, and very recently by Dr. Metz and Professor Putnam in the valley of the Little Miami in Southern Ohio. These discoveries have given new significance to all subsequent glacial investigations in this country. And it is evident, from a moment's consideration, that America presents the best possible field for the determination of the date of the

glacial epoch. In the length of its terminal moraine, in the number of its post-glacial gorges, in the variety of its glacial lakes, America offers unrivalled opportunities for the collection of terrestrial facts bearing on glacial chronology.

2. I confess that the chronological and historical bearing of these investigations are what have given them their chief attractions to me. I am not aware that I have any theological bias. My interest as a Darwinian is as likely to bias me in favor of a short glacial chronology as my reverence for the Bible, for I do not believe that the Bible is committed to any particular scheme of chronology. At any rate, it is important for the truth that the chronology drawn from astronomical theories should be subjected to every possible mode of verification derived from the observation of terrestrial facts.

3. The terrestrial facts brought to light and clearly bearing on the question of the date of the glacial era are much more numerous than they have heretofore been supposed to be. Scarcely more than a beginning has been made in their collection and interpretation; but as far as we have gone, the investigation has been most interesting and suggestive. For the most part these facts imply a later date for the glacial period than the current astronomical theory would admit, and so far they go to disprove that theory.

4. The glaciated area seems a vastly newer country than the unglaciated. In the glaciated region the waterfalls have hardly more than begun to recede; the valleys and gorges are both narrower and shallower than in the unglaciated portion of the country; the lakes and kettle-holes are yet unfilled with sediment, and their outlets have not yet to any great extent lowered the drainage lines; the striated rocks have resisted disintegration to a remarkable degree during post-glacial times, and the moraines and kames have retained their original forms with little signs of erosion. Niagara Falls and the Falls of St. Anthony can neither of them be over 10,000 years old. The waves of Lake Michigan cannot have washed its shores for a much longer time, and the smaller lakes and kettle-holes of New England and the Northwest cannot have existed for the indefinite periods sometimes said to have elapsed since the glacial era, while eternity itself is scarcely long enough for the development of species if the rate of change is no greater than is implied if man and his companions both of the animal and vegetable kingdom were substantially what they are now as long ago as the date often assigned to the glacial period.

5. But while approximate limits are already set to glacial chronology, the field is still open for an indefinite amount of painstaking and accurate inquiry. Local observers may now profitably spend as much time upon a single river valley or in a single county as I have spent upon the whole field between Cape Cod and the Mississippi. As yet there is furnished but the outline of a map whose details need to be worked out with infinite care.

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VIII.

SYLLABUS.

The Existing Glaciers of North America.

1. Present condition of Greenland: investigations of Nordenskiold, Hayes, Kane, Whymper, Rink, Torell, and Helland; motion of the Jacobshavn glacier compared with that of the Muir glacier, Alaska; superglacial streams.

2. Glaciation of the Pacific coast; glaciers of California, Oregon, Washington Territory, British Columbia, and Alaska.

3. Details of my investigations upon the Muir glacier in the summer of 1886: (*a*) Situation; (*b*) Size; (*c*) Motion; (*d*) Recession; (*e*) Buried forests; (*f*) Subglacial transportation.

CONCLUSION.

1. The glacial age has not yet wholly departed. Ice still lingers the year around in Tuckerman's ravine on Mount Washington. Mount Shasta in California still supports vast glaciers on its northern slope. On mounts Hood, Rainier, and Baker the glaciers are of still larger dimensions on every side. In the case of Greenland we have a continental area a third as large as Australia, twenty times the size of Pennsylvania or Ohio, and one hundred times that of Massachusetts, which, with the exception of a narrow fringe along a portion of its southern and western border, is still deeply enveloped beneath glacial ice; while in Alaska immense glaciers come down to the sea-level in the latitude of Northern Scotland and Southern Norway.

2. The accessibility of the Alaskan glaciers makes them objects of special interest to investigators and summer tourists. In a single vacation one can now be transported, without fatigue or exposure and in three week's time, from Boston to the front of some of the largest glaciers which have yet been studied, so that he can see for himself how the streams of ice empty their huge bulk into the sea, and hear with his own ears the booming volleys of sound which announce the birth of an iceberg. But any valuable results in glacial study can only come from a more prolonged stay than is afforded by the excursion steamer.

3. My own investigations upon the Muir glacier fully confirm the observations of Helland as to the rapidity of motion in glaciers of that size. The Muir glacier occupies an amphitheatre estimated to be about thirty-five miles in each of its diameters, thus

covering a space of about 1,200 square miles. From this amphitheatre, sloping down from mountains of about 10,000 feet in height, all the surplus ice is moving towards the head of the Muir Inlet in Glacier Bay, through an opening between the mountains about two miles wide. The motion of the ice in the central part of its channel of exit is from sixty-five to seventy feet per day. The average daily motion of a section one mile wide where it breaks off into the inlet is about forty feet, with a depth of not far from one thousand feet. Making allowance for the diminution of motion in the lower strata of the ice, it is safe to say that 150,000,000 cubic feet of ice are daily discharged during the month of August from this single glacier. A simple calculation will show that an increase of ice left from the summer's melting, of only about two feet, would double the amount compelled to find egress through this narrow outlet to the sea. We should have then at this point, doubtless, a cross-section of ice moving at the above rate two miles wide and fifteen hundred feet deep. With these facts before one's eyes it is not difficult even for the tourist to believe that the whole inlet, and bay, and indeed the whole network of channels and straits characterizing the entire archipelago from Glacier Bay to Puget Sound were at one time filled with moving ice seeking, at every opening, exit to the Pacific.

4. Of this former extension of the glaciers of Alaska and British Columbia there is indubitable evidence in the glacial debris and striæ still preserved far up on the mountain walls of all the fiords; while it is clear that the islands in Puget Sound are nothing but a partially submerged terminal moraine, like Nantucket, Martha's Vineyard, and the Elizabeth Islands, on the New England coast.

5. The broad and connected study which we have been making of the Ice Age in this continent impresses one anew with the marvellous capacity of the human mind to interpret the course of nature, and with the wonderful sagacity of those scientific investigators of the past generation who first broached the glacial theory. After the foundations which Agassiz and his associates laid, it has been easy for many hands under the guidance of his sagacious theory to rear the stately edifice and bring it near to completion. The work grows daily easier as a multitude of observers contribute their fresh stores of fact and lawful inference. In matters of chronology I firmly believe that more may be expected from intelligent and prolonged study of the glacial phenomena in North America than from any other of the many lines of investigation from which light as to man's antiquity has been expected.

December 16.