XVIII.—*Address* by JAMES GEIKIE, LL.D., F.R.S., F.R.S.E.,
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SUBJECT—*The Ice Age in Europe and North America.*

(Delivered 20th November 1884).

IN casting about for a subject upon which to address you this evening, I thought I could hardly do better than give you the result of a comparison which I have recently been able to make between the glacial phenomena of Europe and North America. The subject of glaciation seems to be now somewhat worn, but I gather from the fact that writers can still be found who see in our superficial deposits strong evidence of the Deluge, that a short outline of what we really do know may not be unacceptable. In the short time at our disposal, it is obvious that I cannot enter into much detail, and that many interesting questions must remain untouched. It will be as well, therefore, that I should at the outset define the limits of the present inquiry, and state clearly what are the chief points to which I wish to direct your attention. My main object, then, will be to bring into prominence such evidence as seems to betoken in a special manner the uniformity of conditions that obtained in the Northern Hemisphere during the Ice Age. In other words, I shall confine myself to a description of certain characteristic and representative phenomena which are common to Europe and North America, with the view of showing that the physical conditions of the Glacial Period were practically the same in both continents.

The phenomena which might be considered under this head embrace nearly all the facts with which glacialists are familiar, but I purpose restricting myself to three questions only, viz. :—

- 1st. *The extent of glaciation.*
- 2d. *Changes of climate during the Ice Age; and*
- 3d. *The results of fluvio-glacial action.*

The consideration of these questions, even if it were exhaustive (which it cannot be on this occasion), would still leave the general subject very incomplete, for we must forego the discussion of all such interesting topics as the “connection between glaciation and submergence,” “the formation of rock-basins,” and the “origin of the geographical distribution of our faunas and floras.” Confining my inquiry within the limits just specified, I shall begin by sketching broadly the general results obtained

by glacialists in Europe, and thereafter I shall proceed to give an outline of the corresponding conclusions arrived at by American observers.

I.—*The Extent of Glaciation in Europe.*

To what extent, then, let us ask, has Europe been glaciated? What areas have been covered with perennial snow and ice? Owing to the fulness and clearness of the evidence, we are able to give a very definite answer to this question. It is hardly too much to say that we are as well acquainted with the distribution of glacier-ice in Europe during the Ice Age as we are with that of existing snow-fields and glaciers.

The nature of the evidence upon which our knowledge is based is doubtless familiar to many whom I have the pleasure of now addressing, but for the sake of those who have not such familiarity with the subject, I may be allowed to indicate very briefly its general character. A rock-surface over which ice has flowed for any considerable time exhibits either an abraded, worn, and smoothed appearance, or the rocks are disrupted and broken, and larger or smaller fragments are found to have been removed and carried forward in the direction followed by the ice. Now, ice-worn and shattered rock-surfaces of this description, such as can be seen underneath existing glaciers, occur more or less abundantly over vast regions in Europe. They are met with from the North Cape south as far as Leipzig, and from the Outer Hebrides east to the valley of the Petchora and the foot-slopes of the Ural Mountains. Nor are they confined to Northern Europe. They appear again and again in France and Spain and Italy, and in the low grounds of Middle Europe, where they occupy positions now far removed from the influence of glacial action. Such ice-worn and disrupted rock-surfaces not only prove that glacier-ice formerly covered large portions of our continent, but they also indicate for us the directions in which that enveloping ice moved. The smoother surfaces in question are very frequently marked with coarse and fine parallel scratches and grooves, of precisely the same nature and origin as the scratches and grooves which characterise the rocky bed of a modern glacier. And these markings, having been produced by the sand, grit, and stones which are pushed and dragged over the rocks by flowing ice, necessarily discover for us the path of glacial movement. But all rocks subjected to glacial action are not necessarily smoothed and polished. Sometimes, owing to structural peculiarities, and for various other reasons, rocks cannot resist the pressure of the ice, but are crushed and broken, and the resulting fragments are rolled and dragged

forward in the direction of ice-flow. In this manner the path of a glacier becomes strewn with *débris* which has from time to time been forced from its rocky bed. There is really no mystery, therefore, in tracking the spoor of extinct glaciers; for we have two sets of facts to aid us, either of which might suffice to indicate the extent and direction of glaciation. Consider, however, for a moment, what one observes in connection with rock-striation. We have, in the first place, the rounding and smoothing, and the parallel ruts and striae. Not only so, but we frequently find that one side of prominent projecting knolls and hills is more highly worn and abraded than the other. Often, indeed, one side may show no trace whatsoever of abrasion. Here, again, we have clear evidence of the direction of ice-flow. Who can doubt that the worn and abraded rocks look towards the point whence the ice came, and that the non-glaciated rocks in the rear have been sheltered by the rocks in front? It is for this reason that in the mountainous regions of Northern Europe the striated and smoothed rock-surfaces invariably look up the valleys, while the broken and unworn rock-ledges face in the opposite direction.

Once more, note the manner in which the sub-glacial rock-rubbish, consisting of clay, sand, grit, stones, and boulders, has been amassed. In places where the ice must have moved more or less rapidly, as on considerable slopes, no accumulation took place, while in the rear of projecting crags and knobs of rock, sub-glacial materials often gathered deeply. Again, over low-lying tracts, where the motion of the ice would necessarily be retarded, clay, sand, and stones tended to collect. And this particularly appears to have been the case in those regions where the slow-creeping and gradually thinning ice-sheet approached its terminal line. Hence it is that we encounter such thick and widespread sheets of sub-glacial detritus upon the undulating low grounds and plains of Southern Sweden, Denmark, Schleswig-Holstein, Holland, Northern Germany, Poland, and Russia.

The sub-glacial *débris* to which I specially refer is known as *Till* or *Boulder-clay* in this country, as *Krosstenslera* in Sweden, as *Geschiebe-Lehm* or *Geschiebe-Mergel* in Germany, and as *Grundmoräne* or *Moraine profonde* in Switzerland. Its general characters are too well known to require more than the briefest summary. In general this peculiar accumulation is an unstratified clay, containing, scattered higgledy-piggledy through it, stones and boulders of all shapes and sizes. Many of these rock-fragments are smoothed and striated, and even the smallest particles, when viewed under the microscope, often show delicate scratches. Frequently, too, the clay is excessively hard and tough, and in many places it shows a kind of pseudo-lamination, which is

generally more or less crumpled, and often highly involved. These appearances prove that the clay has not only been subjected to intense pressure, but has actually been rolled over upon itself. I need only refer to the plentiful occurrence of "slickensides" in such clays—the joints by which the clay is often traversed showing such polishing clearly on their faces. These, and many other facts which time forbids me to mention, have received an explanation which has now been generally adopted by European glacialists. The boulder-clay or till is considered by them to represent the ground- or bottom-moraine of glacier-ice. There used to be a notion prevalent amongst geologists in our country that this clay was almost peculiar to these islands. It occurs, however, in most countries of Europe. Vast regions in the north are more or less continuously covered by it, and we meet with it abundantly also upon the low grounds of Switzerland, from which it may be followed far down the great valley of the Rhine into the sunny plains of France. The lower valleys of the Pyrenees and other Spanish ranges show it well, and it is conspicuous likewise in Northern Italy, especially over the low tracts at the mouths of the great lake valleys. In all those places one can see boulder-clay of as pronounced a character as any to be met with in Scotland.

Danish, Dutch, German, and Prussian geologists have of late years devoted much attention to the study of this clay, which is so remarkably developed in their respective countries. It has been long well known that a large proportion of the stones and boulders contained in the till are of northern derivation, but it is only of recent years that we have ascertained the particular routes by which those wanderers or erratics have travelled. The rock-fragments in question have been tracked back, as it were, to their parent masses, and thus, partly in this way, and partly by the evidence of ice-worn surfaces, we have been enabled to follow the spoor of the great northern ice-sheet in a most satisfactory manner. Let one or two examples suffice. Boulders derived from Lapland and Finland occur in the till at St. Petersburg, and have been traced south-east to Moscow. Again, fragments carried from Gottland, in the Baltic, are met with in the boulder-clay of East Prussia, and have been followed south to beyond Berlin. In like manner boulders of well-known Scanian rocks appear in the boulder-clay of Leipzig. So also Swedish and Norwegian rock-fragments are seen in the boulder-clay of Denmark, Hanover, and Holland.

Very wide areas in Northern Germany are covered with an almost continuous sheet of glacial detritus, so that it is only occasionally that the underlying rocks crop out at the surface. Striated rock-surfaces are therefore by no means so commonly

exposed as in regions like the Lowlands of Scotland. They are not wanting, however, and their evidence is very striking. Thus, in the neighbourhood of Leipzig and Dresden, we find glacial striæ impressed upon certain highly-abraded and ice-worn hillocks of porphyry, the striæ being the work of ice which flowed into Saxony from the north. Similar striæ, having a general southerly trend, occur at Rüdersdorf, near Berlin, at Gommern, near Magdeburg, at Velpke in Brunswick, at Osnabrück in Hanover, and at other places. Again, we encounter remarkable evidence of the powerful pressure exerted by the ice in the displacement and removal of huge blocks of strata. In Saxony, for example, the Tertiary strata are turned up, pushed out of place, and involved in boulder-clay to such an extent that the brown coals have often been mined for in this strange position. Witness also the extensive displacements and dislocations of the Cretaceous formation in the Danish islands of the Baltic. So great are the contortions and displacements of the Chalk in Moen, that these disturbances were formerly attributed to subterranean action. Along the north-east coast of that island, cliffs 400 feet in height exhibit the Cretaceous beds thrown upon end, twisted, bent, and even inverted, boulder-clay being squeezed into and between the disjointed and ruptured rock-masses.

From a study of these and similar phenomena, it has been demonstrated that during the climax of the Ice Age a very large part of Northern Europe was buried under a thick covering of glacier-ice. And it has been conclusively shown that this ice-sheet streamed outwards in all directions from the high grounds of Scandinavia, for which reason it is often spoken of as the Scandinavian ice-sheet. But as it was fed not from the snow-fields of Scandinavia alone, but from the precipitation of snow over its whole surface, it is better, I think, to speak of it as the northern ice-sheet. In the extreme north of Scandinavia the ice flowed northward into the Arctic Ocean, while south of the dominant watershed of Lapland and Sweden its course in those high latitudes was east and south-east. It filled up the depressions of the White Sea, the Gulf of Bothnia, and the Baltic, extending east to the valley of the Petchora and the base of the Ural Mountains, and south-east to Kazan, some 200 miles east of Nijnii-Novgorod. From this point its terminal front trended a little west of south, until it reached the fiftieth parallel of latitude. Undulating a few miles south and north of this parallel, it swept directly west through Russia into Galicia, till it touched the foot-hills of the Carpathian range. After this we follow it along the northern base of the Riesen Gebirge, the Erz Gebirge, and the Harz, and thence westward through Hanover, and into

the Low Countries, as far south at least as the mouth of the Rhine. Throughout the vast regions lying west and north of this terminal line, the track followed by the ice has been well ascertained. It was east and south-east in Russia, southerly in East Prussia, south-westerly in Denmark, Hanover, and Holland.

The action of a mass of glacier-ice, reaching a thickness of several thousand feet, must necessarily have resulted in extensive erosion of the rocks over which it passed. Everywhere, therefore, throughout the vast area just indicated, we meet with evidence of severe erosion. But, as one should expect, such erosion is most marked in the hilly regions—in those areas where steep slopes induced more rapid motion of the ice, and where projecting crags and hills opposed the advance of the eroding agent. All such prominent obstructions were energetically assailed,—abraded, rounded, worn, and smoothed, or crushed, shattered, dislocated, and displaced. The high grounds of Scandinavia and Finland, formed for the most part of tough, crystalline rocks, or of more or less durable strata, show everywhere *roches moutonnées*—smoothed and rounded rocks—while innumerable rock-basins have been scooped out in front of prominent crags and hills. In Denmark and other countries, where less durable rocks prevail, the strata have often been broken and disrupted, and pushed out of place. But as regions formed of such rocks are generally gently undulating, and seldom show abrupt crags and hills, they oppose few obstructions to the advance of an ice-sheet. When the northern ice-sheet flowed into Russia and Germany, it crept over a low-lying and, for the most part, gently undulating surface; and although here and there the form of the ground favoured glacial erosion and disruption, and extensive displacements of rock-masses took place, yet, upon the whole, the low-lying regions referred to became areas of accumulation. The sub-glacial detritus—ground out or wrenched away from the rough Scandinavian plateau and the uplands of Finland—was dragged on underneath the ice, and spread over the great plains lying to the south-east and south, as the gradually attenuated ice-sheet crawled to its terminal line. My friend Dr. Amund Helland, the well-known Norwegian geologist, has made an estimate of the amount of rock-*débris* derived from Scandinavia and Finland, which lies scattered over the low grounds of Northern Europe. According to him, the area in Denmark, Holland, Germany, and Russia (exclusive of Finland), over which northern detritus is scattered, contains about 2,100,000 square kilometres, and the average thickness of the deposits is about 150 feet, of which, however, only two-thirds, or 100 feet, are of northern origin, the remaining third consisting of local materials. Taking, then, 100 feet as fairly representing the average thickness of the

rock-rubbish derived from Finland and Scandinavia, the area of which is given as 800,000 square kilometres, there is enough of this material to raise the general surface of those lands by 255 feet. The same amount of material would suffice to fill up all the numerous lakes of Finland and Sweden sixteen or seventeen times over. Or, if tumbled into the Baltic, it would fill the basin of that sea one and a half times. In short, enough northern rock-*débris* lies upon the low grounds of Northern Europe, which, were it restored to the countries from which it has been taken, would obliterate all the lake-hollows of Finland and Sweden, raise the level of those lands by 80 feet, and fill up the entire basin of the Baltic, with all its bays. And yet this estimate leaves out of account all the material which the ice-sheet carried away from Norway and the British Islands.

Of the glaciation of our own land I need say very little. The configuration of our country necessarily made it a centre of dispersion during the Ice Age, and the ice which covered Ireland, Scotland, and the major portion of England radiated outwards from the dominant elevations of the land. But as the ice creeping outwards from those centres became confluent, the directions which it followed were often considerably modified, especially upon the low grounds. We know that the British ice-sheet not only covered the land up to near the tops of our higher mountains, but filled up all our seas and extended into the Atlantic beyond the coasts of Ireland and the Outer Hebrides—these latter islands having been glaciated from the east by the ice that flowed outwards from the mainland. Another point upon which we are now well assured is the fact that the British and Scandinavian ice-sheets coalesced, so that the basin of the North Sea completely brimmed over with glacier-ice.

Finally, then, in contemplating the physical conditions that obtained in Northern Europe at the climax of the Ice Age, we have to picture to ourselves the almost total obliteration under a vast ice-sheet of all the land-features of the British Islands, Scandinavia, and Finland, and the adjacent low-lying tracts of Denmark, Holland, Germany, Poland, and Russia. If at that distant date a pre-historic man could have stood on the summit of Snaehatten, he would have seen an apparently interminable plain of snow and ice, bounded only by the visible horizon. Could he have followed the plain southwards in hopes of escaping from it, he would have descended its gently sloping surface by imperceptible gradations for a distance of 700 miles, before he reached its termination at the foot of the mountains of Middle Germany. Or, could he have set out upon an easterly course, he would have crossed the Gulf of Bothnia, buried several thousand feet beneath him, and touched the foot-slopes

of the Ural Mountains before he gained the terminal front of the ice-cap, a distance of 1600 miles. On the other hand, had he walked south-west in the direction of Ireland, he would have traversed the area of the North Sea at a height of several thousand feet above its bed, and, crossing the British area, would only have reached the ice-front at a point some 50 miles beyond the coast of Ireland. Here he would have seen the ice-sheet presenting a steep face to the assaults of the Atlantic, and breaking away in massive tabular bergs, like those which are calved by the ice-cap of the Antarctic regions.

I must now pass rapidly in review the facts relating to the glaciation of the mountainous regions which lay outside of the area covered by the northern ice-sheet. The glaciers of the Alps of Switzerland, about which so much has been written, and the study of which first gave Venetz, Charpentier, and Agassiz the clue to the meaning of striated rocks, boulder-clay, and erratics, are, as is well known, the puny descendants of former gigantic ice-flows. At the culmination of the Ice Age all the mountain-valleys of Switzerland and Northern Italy were choked with glaciers that streamed out upon the low grounds. Along the northern slopes of the Alps, as in Bavaria and Würtemberg, these glaciers coalesced to form a considerable ice-sheet, and so likewise did the glaciers that descended from Switzerland, Savoy, and Dauphiny into the great valley of the Rhone. Even in North Italy the same was the case with the glaciers that occupied the valleys in which now lie Lakes Orta, Maggiore, Varese, Lugano, and Como—the united ice-flows of those valleys forming a glacier which deployed upon the plains of the Po, with a frontage of not less than 40 miles.

To the north of the Alps, the Vosges Mountains and the Black Forest, the Harz, the Erz Gebirge, the Riesen Gebirge, and the Böhmer-Wald—all had their perennial ice and glaciers, although none of those elevated tracts now reaches the snow-line. It was the same with the Carpathians and the Urals, amongst which we meet with relics of much larger ice-streams than any that now exist in the Alps. Considerably further south were the glaciers of the Despoto Dagh of Roumelia. Great glaciers also in former times descended from the Caucasus, and in many hilly regions of Asia Minor indubitable traces of similar large ice-flows have been detected. The high grounds of Central France, and the mountains of Beaujolais and Lyonnais supported considerable glaciers, while from the Pyrenees numerous glaciers of the first class flowed out upon the low grounds of France, and considerable ice-streams occupied the mountain-valleys on the Spanish side. Other Spanish chains—the Asturian Mountains, the Sierra Guadarama, and the Sierra

Nevada—had likewise their snow-fields and ice-streams. The same was the case with the Apennines and the Apuan Alps of Italy, the traces of former glacial action being conspicuous over a considerable part of Tuscany. Even in Corsica we encounter the same evidence of glaciation—striated rock-surfaces and moraines—which point to the former descent of considerable glaciers from Monte Rotondo.

But rock-striæ and moraines are not the only proofs of former cold and humid conditions, having prevailed over Middle and Southern Europe at the climax of the Glacial Period. The limestone-breccias of Gibraltar have been described by Professor Ramsay and myself, and we have shown that these could only have been formed under the influence of excessive frost and melting snows. The limestone of the Rock has been broken up along the ridge, and its fragments showered down the slopes, at a time when these were more or less thickly covered with snow. Resting upon and imbedded in this snow, the rock-rubbish would be carried downward and outward during the gradual melting that took place in summer. And in this way immense accumulations of *débris* were borne forwards over the low grounds that extended from the base of the Rock into regions which are now partially submerged. Breccias which have probably had a similar origin occur also in Corsica, Malta, and Cyprus, and doubtless they will yet be recognised in many other places. Again, over wide areas in Northern France and the South of England, we meet with extensive sheets of earthy clay and rock-rubbish, which have certainly been heaped up under very different conditions of climate than obtain now. This stony earth has evidently travelled down the gentle slopes of the land, under the influence of frost and melting snow, in much the same way as ice-riven rock-rubbish and soil move slowly down the slopes of such dreary regions as Patagonia and certain low-lying tracts within the Arctic Circle.

II.—*Changes of Climate in Europe during the Ice Age.*

We come next to the very interesting question of alternations of climate during the Ice Age. The evidence under this head has accumulated to such an extent within recent years as to convince every student of Pleistocene geology that very extensive changes of climate characterised the Glacial Period. How many such changes took place we are not yet in a position to say, but we know that the intensely Arctic condition of things which has just been described was interrupted more than once by what have been termed “interglacial epochs,” during which a mild and genial climate prevailed over Middle and Northern Europe.

For some time it was believed that such "interglacial epochs" had only a local significance, that they bespoke mere transitory retreats of the ice-fields, such as are known to have taken place within historical times in the glacier-valleys of the Alps. But increased observation and reflection have shown that this explanation of the phenomena of "interglacial beds" will not suffice. It is impossible to enter here upon details, but I may briefly state that the evidence in question is two-fold. *First*, we have the stratigraphical evidence. We have ascertained the existence, over wide areas in this and other glaciated countries, of several successive sheets of boulder-clay, which are often separated from each other by fossiliferous aqueous strata. It has been demonstrated that each of these sheets of sub-glacial detritus is the accumulation of a separate and distinct ice-flow. *Second*, we have the evidence of fossil organic remains. We find, for example, that the flora which covered the low grounds of Middle and Temperate Europe during a certain stage of the Glacial or Pleistocene Period, consisted of plants which are now restricted to the tops of our mountains and to Northern Scandinavia. The characteristic fauna associated with that flora embraced reindeer, glutton, mammoth, woolly rhinoceros, Arctic fox, lemming, chamois, and so forth. We know, indeed, that man hunted the reindeer and the mammoth in the south of France. Similar testimony to the coldness and humidity of the climate is borne by the land- and fresh-water shells which occur in certain Pleistocene deposits in Italy, Corsica, Southern France, Switzerland, Germany, &c. That this flora and fauna were contemporaneous with the great glaciation of our continent has been as well ascertained as the fact of the Roman occupation of Britain. But if the evidence of organic remains strongly confirms and supports that supplied by the distribution of glacial deposits in Europe, no less forcibly does it corroborate the physical evidence as to the former existence of a warm and genial interglacial climate. During interglacial times a most abundant mammalian fauna roamed over all temperate Europe—a fauna comprising such animals as Irish deer, urus, bison, horse, stag, saiga, brown bear, grisly bear, several species of elephant, rhinoceros, and hippopotamus, hyæna, lion, leopard, &c. A like tale of genial conditions is told by the land- and fresh-water shells, which occur in some of the Pleistocene deposits of England, France, Belgium, Germany, Switzerland, and Italy. The testimony of the associated flora is just as striking. How genial and equable must have been the climate which permitted plants like the Canary laurel, the Judas-tree, the fig-tree, and others to flourish side by side in the north of France, with such forms as the hazel, willow, ash, and sycamore!

The most noteworthy additions to our knowledge of interglacial conditions which have recently been made are the results obtained by M. Gaudry in the valley of the Seine, and by Dr. Penck in Bavarian Tyrol, the latter of whom has shown that there have been at least three great advances of the Alpine glaciers, separated by long-continued mild conditions, during which the glaciers receded far into the mountains.

It is interesting to observe that we have, especially in our own islands, good evidence to show that during the Glacial Period considerable oscillations of the relative level of land and sea took place. Thus, it has been ascertained, that just before the latest epoch of extensive glaciation, the British Islands were largely submerged in the sea. To what depth this remarkable submergence was carried we do not know, because any marine deposits which may have been accumulated at that time over the drowned country were for the most part obliterated by the action of the ice-sheet, which subsequently covered and reglaci-ated our lands. But the few fragments of such marine deposits as have been preserved show us that the depression reached more than 500 feet in Scotland (*i.e.*, measured from the present sea level), and exceeded 1000 feet in Wales and Ireland. We note, then, in passing, that the only great Pleistocene submergence of these lands of which geologists have any knowledge took place before the appearance of the last ice-sheet that overflowed our low grounds. The submergences of a later date were of inconsiderable importance, hardly exceeding 100 feet or thereabouts below the present sea level. The latest occupant of our islands and of Northern Europe was not the sea, but ice. The "Palæocrystic Sea," which we have been recently assured would account for our glacial phenomena, is of "the stuff that dreams are made of." There is not a jot or tittle of evidence for the former existence of such a sea over any part of Britain or the continent of Europe.

It is not necessary for my present purpose to enter further into the evidence of interglacial conditions. The latest northern ice-sheet was preceded by a long epoch of mild and genial conditions, during which elephants and hippopotami ranged north as far at least as Yorkshire; while Middle Germany, as we know from the testimony of its interglacial deposits, enjoyed a similar delightful climate. And yet the immediately preceding glacial epoch had seen all those fertile regions covered with an ice-sheet that extended south as far as the fiftieth parallel of latitude. Now the question with which I am at present concerned is the extent of the latest glaciation. Did the last ice-sheet reach as far south as its predecessor? It certainly did not. Its bottom-moraine has now been mapped out and distinguished

from that of the older ice-sheet, and we know that it does not extend so far south as the latter. It is entirely absent over all the region to the west of the River Elbe, from near Dresden to Hamburg and the coast of Holland.¹ So that Western Germany and Holland, which were covered by ice during the epoch of greatest glaciation, were not invaded by the ice-sheet underneath which the upper boulder-clay was accumulated. This latest ice-sheet, however, overwhelmed all Mecklenburg and Mark Brandenburg, and streamed south nearly as far as Saxony; its southern margin extended east through Silesia, by Liegnitz and Breslau, into Poland and Russia. But the precise line it followed in the latter country has yet to be ascertained. We may surmise, however, that it nowhere reached so far south or east as the ice-flow of the earlier epoch. I may add that the southern termination of the latest ice-sheet is in many places marked out by heaps, mounds, and ridges of earthy sand, gravel, rolled stones, and erratics; in short, by terminal moraines. These, however, are frequently highly degraded and washed down.

Of the extension of glacier-ice in the British Islands at the epoch in question I shall only say that the glaciation of Scotland was hardly, if at all, less extensive than during the climax of the Ice Age. Ireland, too, appears to have been almost as thickly mantled; but the ice-sheet that covered England and Wales did not extend so far south as that of the penultimate glacial epoch, a considerable area in East Anglia and the Midland counties remaining apparently free from invasion. The Scandinavian and British ice-sheets, however, again coalesced upon the floor of the North Sea.

III.—*The Results of Fluvio-glacial Action in Europe.*

The third question which I now proceed to consider is the result produced by the rivers and torrents of the Ice Age. This, I am aware, is a wide subject, and one upon which much has been written. But there are a few points which may be advantageously discussed for the purpose of bringing into prominent view the conditions which obtained in the river-valleys of Europe during the last great extension of glacier-ice.

A little consideration will serve to convince one that the intense glacial conditions that obtained in our continent during the cold epochs of the Glacial Period were due to a low temperature, combined with excessive snow-fall. The winters, we can have no doubt, must have been prolonged and severe. But mere low temperature will not account for the enormous pre-

¹ Klockmann, *Jahrb. der K. preuss. geol. Landesanstalt für* 1883, p. 330.

cipitation of snow. For this, great evaporation was required. And we are therefore forced to admit that the direct heat of the sun in summer must have been greater than it is in the same regions at the present day. Now, if this were really the case (and I do not see how otherwise the facts can be explained), then we ought to meet with evidence of swollen rivers, torrents, and wide-spread inundations everywhere outside of the glaciated areas. And this is precisely what we do find. Immense accumulations of coarse gravels are widely spread over all the valleys that head in regions which were formerly the sites of snow-fields and glaciers. These gravels are of such a character and are so distributed as to make it certain that they could not have been transported to and deposited in their present positions by rivers like those which now wind their way down the valleys of Middle Europe. Still more remarkable are the enormous sheets of loam which are spread over much wider areas and reach to more considerable heights than the gravels. The origin of the gravels is sufficiently evident; they are simply the coarser detritus, swept along by the enormously flooded rivers of the Glacial Period, and meet with their analogues in the torrential gravels of modern glacier-valleys in the Alps and other elevated regions. The more widely-spread loams, according to the opinion of most glacialists, represent the finer mud and silt deposited from the muddy waters of the same period. But the height to which such gravels and loams ascend is so great that those who hold them to be of fluvio-glacial origin have found it difficult to maintain this view. Some writers, indeed, who have not sufficiently considered the weight of the evidence in its favour, have set it aside, and boldly suggested all kinds of wonderful hypotheses in its place. One imaginative author, for example, believes the wide-spread loams to be of volcanic origin, while another finds in the same deposits strong evidence of the Deluge. By a better-informed and more reliable author, the famous löss of Middle Europe is considered to be an Æolian accumulation,—that is to say, a wind-blown deposit—the result of long-continued or frequently repeated dust-storms. This is the opinion of Baron Richthofen, whose great work on China is so highly esteemed. He infers that at the time of the formation of our löss Central Europe was a dry dessicated region, just as wide areas in Central Asia are in our own day. He does not attempt to show us, however, how such climatic conditions could ever obtain in Europe. In point of fact, the geographical position of our continent, which has not changed materially since Pleistocene times—the presence of the wide Atlantic Ocean, that laves all our western shores—this of itself is sufficient to preclude the possibility of such a climate having obtained in

Middle Europe. Richthofen's theory likewise fails to account for the geographical distribution of the löss, and for many facts relating to its geology. Only one of these last shall I mention. The löss is intimately associated with accumulations, the glacial and fluvio-glacial origin of which cannot be doubted. It belongs, in fact, to the glacial series, and was laid down at a time when vast snow-fields and ice-sheets existed, and when it is quite impossible that a dry climate could have characterised any part of our continent. In common with most geologists, I believe that the löss is simply an inundation-mud, deposited in temporary lakes and over flooded areas during the summer meltings of the snow and ice-fields; and I shall now try to show how the occurrence at high levels of gravels and such loams as the löss may be accounted for without having recourse either to volcanic action or to winds, or even to the Deluge. I shall invoke no agencies other than those which we are perfectly well assured were in full operation during the Ice Age.

Now, I ask you, in the first place, to bear in mind that while a glacial epoch continued, extreme conditions could not have been restricted to the areas undergoing glaciation. There is abundant evidence, indeed, to show that heavy snows occasionally covered other regions, and that in such places severe frosts acted upon the rocks and soils even of the low grounds. Need we wonder if at a time when the northern ice-sheet approached the fiftieth parallel of latitude in Middle Europe, when almost every mountain-group of Central and Southern Europe had its snow-fields and glaciers—need we wonder if at such a time the climate of wide areas outside of the glaciated tracts was extremely ungenial? The more closely the superficial accumulations of such areas are studied, the more clearly do we perceive in them the evidence of cold and humid conditions. Try, then, to picture to yourselves the probable aspect of those regions during a glacial epoch. Immediately south of the northern ice-sheet deep snows must have buried large tracts of country, and such snows may have endured often for long years, notwithstanding the great melting that took place in summer. Even much further south, as in Spain and Italy, deep snows would cover the lesser hills and hill-ranges, while frost would act energetically in many a district where such action is now either inconsiderable or unknown. Such being the general conditions that must have obtained in the non-glaciated areas, let us very briefly consider what the results of such conditions must necessarily have been. Every one has noticed, during the more or less rapid melting of snow in winter and early spring, that our streams and rivers are then much muddier than when in summer and autumn they are swollen by heavy rains. This of course is

due to the action of frost, by means of which rocks are dis-integrated and soils are broken up and pulverised, so that when thaw supervenes, the superficial covering becomes soaked with moisture like a sponge. To such an extent does this take place, that one may often see the saturated soil creeping, slipping, and even flowing down the slopes. The effect of mere thaw is of course much intensified when the water derived from melting snows is present. Rills and tiny brooks then become converted into dark muddy torrents, and enormous quantities of fine-grained detritus are eventually swept into the rivers. The rivers rise in flood and inundate their plains, over the surface of which considerable deposits of loam and silt often accumulate. We cannot doubt that similar but much more intense action must have taken place over very wide regions in Europe during a glacial epoch. Such having necessarily been the case, we are not required to suppose that the löss and similar loams have been deposited entirely by rivers flowing from glaciers. It is doubtless true that most of the rivers headed in those days in glacier regions, and must in consequence have been highly dis-coloured with glacial mud, and probably a very large proportion of the loams in question consists of the fine flour of rocks—the result of glacial grinding. But the action of frost and thaw and melting snow upon the low grounds, such as I have described, cannot be ignored, and seems to have played a more important rôle than has yet been fully recognised. I think it helps us better to explain the well-known fact that land-shells are more or less commonly distributed through the löss. One can readily understand, at all events, how snail-shells might be swept down the slopes of the land at the time of the spring thaws, and how large numbers might find their way eventually into the swollen glacial rivers. I have often observed during the melting of snow and thawing of the soils quantities of snail-shells in the very act of being swept into our brooks and rills. And we are all familiar with the fact that, after a spring-flood has subsided, snail-shells, along with vegetable *débris*, are often plentifully stranded upon the valley-slopes and flood-plains of our rivers.

Admitting, then, that the löss and similar accumulations are simply inundation-loams formed at a time when glaciers were discharging immense volumes of muddy water, and when the low grounds were liable every summer to the denuding action of melting snows, and so forth, I have yet to account for the fact that these supposed inundation-loams sometimes occur at a height of 100 feet, or even of 300 feet, above the present level of the rivers. Two theories have been advanced in explanation, each of which seems to me to contain an element of truth. It has, in the first place, been maintained, as by Prestwich, that

the löss at the higher levels was probably deposited long before the rivers had excavated their channels to their present depths. Thus, during flood, they would be enabled to overflow tracts which they could not possibly have reached when they had deepened their valleys to a much greater degree. But while we must fully admit that the erosion effected by the rivers of the Pleistocene or Glacial Period was excessive, yet we find it difficult or impossible to believe that great valleys, several miles in width, and two or three hundred feet in depth, were excavated in hard Devonian and other equally durable rocks by the swollen and active rivers of the Ice Age. And although it is extremely probable that the löss at the highest levels is older than the similar deposit at the lowest levels of such a valley as the Rhine, yet this does not get us out of our difficulty.

The other view to which I have alluded takes little or no account of river erosion, but maintains that the floods of the Ice Age were sufficiently great to reach the highest levels at which river gravels and loams occur. It is likely enough that, under present conditions, we can form but a very inadequate idea of the vast bodies of fresh water which formerly swept down our valleys, but we may be pardoned if we express our inability to conceive of our European rivers flowing with a breadth of many miles, and a depth of 200 feet or 300 feet.

A few years before his death, Mr. Darwin made a suggestion to me, which I think gives us the true solution of the problem. He thought that during an Ice Age great beds of frozen snow might have accumulated over the low grounds outside of the glaciated areas (in the manner I have already described), and that many valleys might have been filled to a considerable depth during a large part of the year with blown snow, afterwards congealed. In autumn, when the running water failed, the lines of drainage might in many cases be more or less choked, and it would be a mere chance whether the drainage, together with gravel, sand, and mud, would follow precisely the same lines during the next summer. Such action being repeated year after year, it might well happen that many river-valleys might become largely filled with rudely alternating layers of frozen snow and fluvial detritus. And if this were so, the flooded rivers in summer would be enabled to overflow much wider and more elevated tracts than they could otherwise have reached. As the climate became less excessive, we can conceive of the frozen snows gradually melting, and of river-detritus being deposited at lower and lower levels in the valleys.

The probability of such frozen masses having choked up valleys and impeded the drainage during the Ice Age is not a mere plausible conjecture. In the far north of Alaska—in a

region which was certainly not overflowed by the North American ice-cap—extensive sheets of ice occur, more or less deeply buried under thick soil. Nor can there be much doubt that these ice-masses date back to the Glacial Period itself, seeing that in the soils which overlie them we meet with remains of the mammoth and other contemporaneous mammalian forms. Here, then, we have direct proof of the fact of frozen snow and ice having accumulated in the hollows of the land outside of the glaciated areas.¹

Now, if such conditions existed in the valleys of Middle Europe, the wide-spread löss of those regions is readily accounted for. The occurrence of irregular sheets and shreds of gravel and loam at heights of more than a hundred feet above a valley-bottom offers no difficulty—it is in fact precisely the kind of phenomenon we might have expected. We are therefore not required to go out of our way to dream about impossible volcanic action, or to call upon the winds of heaven to help us, or upon the waters of the Deluge to float us out of our difficulties. But while I believe the views I have now advocated sufficiently account for the appearances presented by the ancient valley-gravels and loams of Central Europe, there are two very considerable areas of löss which require some further explanation. The first of these is that broad belt of löss which extends from west to east across the plains of Northern Germany, and the northern boundary of which coincides with the limits reached by the last great ice-sheet, from which it spreads south to the foothills of the Harz, and other mountains of Middle Europe. Here we have a sheet of löss which bears no apparent relation to the valley-systems of the region in which it occurs. But the fact of its northern boundary being coincident with the terminal front of the last great northern ice-sheet at once suggests its origin. It is evident that this ice-sheet must have blocked the rivers flowing north, and dammed back their waters.² A wide sheet of muddy water must therefore have extended east and west over the very area which is now covered by the belt of löss in question. This temporary lake would doubtless be subject to great alternations of level—a portion draining away perhaps under the ice-sheet—but the water would for the most

¹ I have given Mr. Darwin's views, and discussed the origin of the Pleistocene fluvio-glacial deposits at some length in "Prehistoric Europe," chaps. viii. and ix. To this work I refer for detailed geological evidence in support of the view advocated above.

² The late Mr. Belt, as is well known, was of opinion that all the rivers flowing north in Europe and Asia were dammed back by a great Polar glacier, and that all the low tracts in the northern portions of the two continents were thus covered by wide inland seas of fresh water. As I do not believe that such a Polar ice-cap existed during the Glacial Period, I cannot agree with Mr. Belt that the alluvial plains of Northern Siberia mark the sites of ice-dammed lakes.

part make its way westward, and eventually escape into the English Channel. From the waters of this great lake, fed by many large glacial rivers, abundant precipitation of loam and silt must have taken place.

The second, and by far the most extensive, sheet of löss in Europe is the so-called "black earth," or "tchernozem," with which such enormous tracts in Southern Russia are covered. This wide-spread löss—for such it really is—I have elsewhere tried to show consists of the flood-loam and inundation-muds laid down by the water escaping along the margin of the northern ice-sheet, which discharged its drainage in the direction of the Black Sea, its black colour being due to the grinding down and pulverising of the black Jurassic shales which extend over such wide regions in Middle Russia.

IV.—*The Extent of Glaciation in North America.*

The various phenomena of glaciation, which go to prove that a great ice-sheet formerly covered a wide region in Northern Europe, are developed on a still more extensive scale in North America. Smoothed and striated rock-surfaces, crushed and dislocated rock-masses, and enormous accumulations of morainic *débris* and fluvio-glacial detritus, all combine to tell the same tale. The morainic accumulations of North America have been distributed upon the same principles as the similar deposits of our own continent. Boulder-clay of precisely the same character as that of Scotland and Scandinavia, of Switzerland and North Italy, covers vast tracts in the low grounds of the British Possessions and the Northern States of the Union, where it forms enormous sheets, varying in thickness from 30 or 50 up to 100 feet or more. In the rough Laurentian Highlands, however, it is more sparingly developed, and the same is the case in the hilly regions of New England. In short, it thickens out upon the low grounds, and thins off upon the steeper slopes, while it attains its greatest thickness and forms the most continuous sheets in the country that lies south of the great lakes.

The southern limits of this deposit form a kind of rude semi-circle. From New York the boundary line has been followed north-west through New Jersey and Pennsylvania to beyond the forty-second parallel, after which it turns to the south-west, passing down through Ohio to Cincinnati (39°); then, striking west and south-west through Indiana, it traverses the southern portion of Illinois. Its course, after it reaches the valley of the Missouri, has been only approximately determined, but it

certainly turns at last rather abruptly to the north-west, sweeping away in that direction through Kansas Nebraska, Dakota, and Montana.

The general course followed by the ice-sheet underneath which this boulder-clay was formed has been well ascertained, partly by the evidence of the clay and its contents, and partly by that of *roches moutonnées* and ice-worn rocks. The observations of geologists in Canada and the States leave it in no doubt that an enormous sheet of ice flowed south over all the tracts which are now covered with boulder-clay. During a recent visit to Canada and the States, I had opportunities of examining the glacial deposits at various points over a somewhat extensive area, and everywhere I found the exact counterparts of our own accumulations. In Minnesota, Wisconsin, Iowa, Illinois, Indiana, and Ohio, and again in New York, Connecticut, and Massachusetts, and the low grounds of Canada, I recognised boulder-clay of precisely the same character as that with which we are familiar at home. The glacial phenomena of the Hudson valley and of the lower part of the Connecticut River were especially interesting. In those regions the evidence of a southward flow of the ice is most conspicuous, and the phenomena, down to the smallest details, exactly recalled those of many parts of Europe. Professor Dana, under whose kind guidance I visited the Connecticut valley, showed me, at a considerable height upon the valley slope, an ancient water-course, charged with gravel and shingle, which could not possibly have been laid down under present conditions. It was, in fact, a sub-glacial water-course, and resembled the similar water-courses which are associated with boulder-clay in our own country.

If I met with only familiar glacial phenomena in the low-lying tracts traversed by me, I certainly saw nothing strange or abnormal in the hillier tracts. In passing over the dreary regions between the valley of the Red River and Lake Superior, I was constantly reminded of the bleak tracts of Laurentian gneiss in the north-west of Scotland, and of the similar rough broken uplands in many parts of Scandinavia and Finland. The whole of that wild land is *moutonnée*. Rough tors and crags are smoothed off, while boulder-clay nestles on the lee-side. In the hollows between the *roches moutonnées* are straggling lakes and pools and bogs innumerable. Frequently, too, one comes upon rounded cones and smooth banks of morainic gravel and sand, and heaps of coarse shingle and boulders, while erratics in thousands are scattered over the whole district. If you wish to have a pretty fair notion of the geological aspects of the region I refer to, you will find samples of it in many parts of the Outer Hebrides and Wester Ross-shire and Sutherland.

Cover those latter districts with scraggy pines, and their resemblance to the uplands of Canada will be complete.

From the descriptions given by travellers, it would appear that morainic detritus—mounds and sheets of stony clay, gravel and sand, shingle, boulders, and erratics—are more or less plentifully sprinkled over all the British Possessions and the islands of the Arctic Archipelago. So that we have every reason to believe that the ice-sheet which left its moraines at New York and Cincinnati extended northwards to the Arctic Ocean. Nor can there be much doubt that this same *mer de glace* became confluent in the west with the great glaciers that streamed outwards from the Rocky Mountains; while we know for a certainty that the southern portion of Alaska, together with British Columbia and Vancouver Island, were buried in ice that flowed outwards into the Pacific.

Along the eastern seaboard north of New York City there is no tract which has not been overflowed by ice. The islands in Boston Harbour are made up for the most part of tough boulder-clay; and boulder-clay and striated rocks occur also in Maine, New Brunswick, Nova Scotia, and Newfoundland.

Thus we may say that the ice-covered region of North America was bounded on the north by the Arctic, on the west by the Pacific, and on the east by the Atlantic Oceans. The Rocky Mountains, however, divided the great *mer de glace* that overflowed Canada and the States from the ice that streamed outwards to the Pacific. Measured from the base of the Rockies to the Atlantic, the *mer de glace* of Canada and the States must have exceeded 2500 miles in width, and it stretched from north to south over 40 degrees of latitude.

Outside of this vast region and the great mountain-ranges of the far west, there are few hilly areas in the States which reach any considerable elevation. South of the *mers de glace* of the north and west, no such mountain-groups as those of Middle and Southern Europe occur, and consequently we do not expect to meet with many traces of local glaciation. Nevertheless, these have been recognised in the Alleghany Mountains, West Virginia, and in the Unaka Mountains, between Tennessee and North Carolina. But the glaciers of those minor hill-ranges were of course mere pigmies in comparison with the enormous ice-streams that flowed down the valleys of the Rocky Mountains and the Sierra Nevada. Even as far south as the Sierra Madre of Mexico glaciers seem formerly to have existed; and Mr. Belt has described the occurrence of true boulder-clays at a height of 2000 to 3000 feet in Nicaragua.

I have mentioned the fact that in Europe we have, outside of the glaciated areas, certain accumulations (such as the Gibraltar

breccias) which could only have been formed under the influence of extreme cold. Similar accumulations occur in North Carolina, where they have been carefully studied by Mr. W. C. Kerr. According to Mr. Kerr, these deposits have crept down the declivities of the ground under the influence of successive freezings and thawings; and now that attention has been called to such phenomena, our American friends will doubtless detect similar appearances in many other places.

The facts which I have now briefly indicated suffice to show that during the climax of glaciation North America must have presented very much the same appearance as Europe. Each continent had its great northern ice-sheet, south of which local glaciers existed in hilly districts, many of which are now far below the limits of perennial snow. We may note, also, that in each continent the *mers de glace* attained their greatest development over those regions which at the present day have the largest rainfall. Following the southern limits of glaciation in Europe, we are led at first directly east, until we reach Central Russia, when the line we follow trends rapidly away to the north-east. The like is the case with North America. Trace the southern boundary of the ice-sheet west of New York, and you find, when you reach the valley of the Missouri, that it bends away to the north-west. Now we can hardly doubt that one principal reason for the non-appearance of the *mer de glace* in the far east of Europe and the far west of America was simply a diminishing snow-fall. Those non-glaciated regions which lay north of the latitude reached by the ice-sheets were dry regions in glacial times, for the same reasons that they are dry still. The only differences between glacial Europe and America were differences due to geographical position and physical features. The glaciation of the Urals was comparatively unimportant, because those mountains, being flanked on either side by vast land-areas, could have had only a limited snow-fall; while the mountain-ranges of Western North America, on the other hand, being situated near the Pacific, could not fail to be copiously supplied. For obvious reasons, also, the North American ice-sheet greatly exceeded that of Europe. In all other respects the conditions were similar in both continents.

V.—*Changes of Climate in North America during the Ice Age.*

American geologists are now pretty well agreed that their “interglacial deposits”—the existence of which is not disputed—have precisely the same meaning as the similar deposits which occur in Europe. They tell of great climatic changes. At

present, however, there is no certain evidence in the American deposits of more than one interglacial epoch; but the proofs of such an epoch having obtained are overwhelming. The occurrence again and again of fossiliferous beds intercalated between two separate and distinct sheets of boulder-clay and morainic accumulations, leaves us in no doubt that we are dealing with precisely the same phenomena which confront us in Europe. No mere partial recession and readvance of the *mer de glace* will account for the facts. We have seen that during the culmination of the Glacial Period the American ice-sheet overflowed Ohio, Indiana, and Illinois. Now interglacial deposits occur as far north as the Canadian shores of Lakes Ontario and Superior, so that all the country to the south must have been uncovered by ice before those interglacial deposits were laid down. But the evidence entitles us to say much more than this. The interglacial beds of Ohio, Indiana, Illinois, and other States, afford abundant evidence of a great forest-growth having covered the regions vacated by the ice of the penultimate glacial epoch. The trees of this forest-land included sycamore, beech, hickory, red cedar, and others; and amongst the plants were grape vines of enormous growth, which, according to Professor Cox, "indicate perhaps the luxuriance of a warmer climate." At all events, the climate that nourished such a forest-growth could not have been less genial than the present. And such being the case, we may reasonably infer that the vast regions to the north of the lakes were no more inhospitable then than they are now.

To this genial interglacial epoch succeeded the last glacial epoch, when a great ice-sheet once more enveloped a wide area. In the extreme east this latest *mer de glace* appears to have reached as far south as that of the earlier epoch; but as we follow its terminal moraines westward, they lead us farther and farther away from the southern limits attained by the preceding ice-sheet. These vast terminal moraines form an interesting study, and the general results obtained by American observers have been very carefully put together by Professor Chamberlin. I traversed wide regions of those moraines in Indiana, Illinois, Wisconsin, and Minnesota, and, so far as my observations went, I could only confirm the conclusions arrived at by Professor Chamberlin and others. The mounds, banks, cones, and ridges are unquestionably moraines—of enormous dimensions, no doubt—but in all their phenomena strictly analogous to similar gravelly moraines in our own country and the continent. Many of the American moraines consist almost entirely of water-worn material—sand, gravel, shingle, and boulders, together with large angular and sub-angular erratics. These deposits are generally

stratified, and frequently show diagonal or false-bedding. In this and other respects they exactly reproduce—but of course on a much larger scale—our Scottish kames, and the similar accumulations of North Germany and Poland, and the low grounds of Italy opposite the mouths of the great Alpine lakes. The kames of Wisconsin again and again reminded me of the gravelly moraines that cover the ground for many miles round the lower end of Lake Garda. It is this gravelly and sandy aspect of the American moraines that is most conspicuous, for it everywhere seems to form their upper and outer portions. Now and again, however, a deep cutting discloses underneath and behind the stratified water-worn detritus a mass of confused materials, consisting of clay, sand, gravel, shingle, and boulders, which are angular and sub-angular, often smoothed and striated, and of all shapes and sizes. According to Mr. Chamberlin, this unstratified material “is indistinguishable from true till, and is doubtless to be regarded as till pushed up into corrugations by the mechanical action of the ice.”

This grand series of moraines stretches from the peninsula of Cape Cod across the Northern States, and passes in a north-westerly direction into the British Possessions, over which it has been followed for some 400 miles. The disposition of the moraines, forming as they do a series of great loops, shows that the ice-sheet terminated in a number of lobes or gigantic tongue-like processes. Nothing seen by me suggested any marine action; on the contrary, every appearance, as I have said, betokened the morainic origin of the mounds; and Mr. Chamberlin assured me that their peculiar distribution was everywhere suggestive of this origin. No one who has traversed the regions I refer to is at all likely to agree with Sir W. Dawson's view, that the American mounds, &c., are the shore-accumulations of an ice-laden sea.

The morainic origin of these accumulations having been demonstrated by American geologists, we are now able to draw another parallel between the European and American glacial deposits. We have seen that in Europe the ice-sheet of the latest glacial epoch was by no means so extensive as that of the preceding glacial epoch. The same was the case in North America. Moreover, in America, just as in Europe, the latest occupant of the land was not the sea, but glacier-ice. In Scotland and Scandinavia, the gradual disappearance of the continental ice-sheet was marked by a partial submergence, which, in the former country, did not greatly exceed 100 feet, and in the latter 700 feet. In America, in like manner, we find traces of a similar partial submergence. In Connecticut this did not exceed 40 or 50 feet, but increased to some 500 feet in the St. Lawrence, and to over 1000 feet in the Arctic regions. If there ever was

during the Glacial Period a greater submergence than this in North America, it must have taken place in interglacial times, but of such a submergence no trace has yet been recognised. In this respect the American record differs somewhat from our own,¹ for in Britain we have distinct evidence of a submergence of over 1000 feet, which supervened in times immediately preceding the latest great extension of continental ice. But nowhere in Middle Europe, and nowhere in North America, in the region south and west of the great lakes, is there any trace of a general marine submergence. The "Palæocrystic Sea" is as idle a dream for the Northern States of America as it is for any part of Europe.

VI.—*The Results of Fluvio-glacial Action in North America.*

The close analogies which obtain between the glacial and interglacial deposits of Europe and North America are equally characteristic of the fluvio-glacial accumulations of the two continents. As in Europe, so in America we meet with wide-spread sheets of gravel and shingle, sand, fine clay and loam, which are evidently of fresh-water origin. In the gently undulating tracts of the Northern States those deposits often spread continuously over vast regions; in the hillier districts, however, they are most characteristic of the valleys. They are very well represented, for example, in the Connecticut valley, where they have been carefully studied by Professor Dana. Like the similar deposits of our own continent, they have been laid down by the torrents and swollen rivers of the Glacial Period. The great range of moraines which marks the extreme limits reached by the latest ice-sheet is generally associated with sheets of gravel and sand, which one can see at a glance are of contemporaneous origin, having been spread out by the water escaping from the melting ice. Nor can one doubt that the vast sheets of löss in the Missouri and Mississippi valleys are strictly analogous in origin, as they are in structure and disposition, to the löss of Europe. I have spoken of the probable existence of a glacial lake formed by the damming back of the Rhine and other rivers by the European ice-sheet. Now, in North America we meet with evidence of the same phenomenon. When the last ice-sheet of that continent attained its maximum development, all the water escaping from its margin in the North States necessarily flowed south into the Mississippi and Missouri rivers. But in course of time the ice melted away beyond the

¹ I have sometimes thought it possible, however, that some of the marine clays of North America may really be of older date than the upper boulder-clay of the same regions; that, in short, these may yet be in part correlated with the high-level marine drifts of the British area.

drainage-area of those rivers, and disappeared from the valley of the Red River of the North, which, it will be remembered, empties itself northward into Lake Winnipeg. When the ice-front had retired so far, it naturally impeded the drainage of the Red River basin, and thus formed a vast glacial lake, the limits of which have been approximately mapped out by Mr. Upham, by whom the ancient lake has been designated Lake Agassiz. The deposits laid down in this lake consist of finely laminated clays, &c., which resemble in every particular the similar unfossiliferous clays so frequently found associated with glacial accumulations in Europe. Had the drainage of the Red River valley been south instead of north, the clays and loams of the far North-west would not have been arrested and spread out where they now are, and Manitoba would have been covered for the most part with loose shingle, gravel, and sand.

Thus the final disappearance of the American ice-sheet was marked by the formation not only of moraines, but of flood-gravels and torrential and inundation-deposits of the same character as those with which we are familiar at home. Wherever similar geographical conditions prevailed, there similar geological results followed.

VII.—*Conclusion.*

There are many other points of resemblance between the glacial and fluvio-glacial accumulations of the two continents, but to these time forbids any reference. Indeed, I cannot recall any signal difference. Such differences as do occur are due simply to the varying conditions of the two continental areas. The glacial phenomena of North America are a repetition of those of Europe, but upon a much grander scale. The boulder-clays of the former continent, in their composition, structure, and distribution, exactly recall our own. Interglacial beds occur under similar circumstances in both continents; and the same is the case with the gravelly moraines and fluvio-glacial accumulations. We are driven, then, to the conclusion that the physical conditions of the Glacial Period were practically the same in Europe and North America. What those conditions were I have already indicated, and have shown that the results arrived at by geologists are not vague dreams and speculations, but a logical induction from well ascertained facts. Before we can believe that volcanic eruptions, a general deluge, or a Palæocrystic Sea have produced the many varied phenomena of our glacial formations, either in whole or in part, we must first shut our eyes and then erase from our minds all knowledge of the facts which have been so laboriously gathered by a long succession of competent observers.