THE

CLIMATIC CHANGES

OF LATER GEOLOGICAL TIMES:

A DISCUSSION BASED ON OBSERVATIONS MADE IN THE CORDILLERAS OF NORTH AMERICA.

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CHAPTER I.

THE GLACIAL AND SURFACE GEOLOGY OF THE PACIFIC COAST.

SECTION I.— *Introduction.*

THIS chapter and the following one form the basis on which the present volume rests. They were originally intended to be included in a work entitled "The Auriferous Gravels of the Sierra Nevada of California," a part of which has been already published, while the appearance of the remaining portion will not be much longer delayed.* The reason why it has been decided to make a separate work of the glacial geology is, that the quantity of matter was found to be unexpectedly large, so that a volume which should contain the whole results of the investigation would be inconveniently bulky. The gravel deposits of the Sierra Nevada do, indeed, form a special subject of inquiry, and a single volume may most properly be devoted to their exclusive consideration. Moreover, by separating the discussion of the glacial phenomena from the description of the auriferous gravels, a wider range could be given to the former, which course seemed, after the writing out of the work for publication had been taken seriously in hand, to be most desirable.

The study of the mode of occurrence of the formations described in the gravel volume led the writer to form certain conclusions with regard to the physical conditions prevailing during the epoch of their deposition.† It seemed to him to be most clearly made out that a precipitation, greatly in excess of that which is now taking place in the same region, was the most important agent in bringing about the accumulation of those great masses

* That work will be cited in the present one as the "Auriferous Gravels," or simply as the "gravel volume." It forms the sixth volume of the Memoirs of the Museum of Comparative Zoölogy.

† See Chapter IV, sections 5 and 6 of the Auriferous Gravels.

of detrital materials whose geological peculiarities as well as whose richness in gold has made them so interesting to scientific and practical men. That the climate, during this period of greater rain-fall, was warmer than it now is, appears also to have been proved by the character of the vegetation prevailing during deposition of the gravel.

But in the course of the investigations of the California Survey it long ago became evident that the present epoch is one of desiccation; or, in other words, that there has been, during the most recent geological times, a constant diminution in the quantity of the water standing and flowing upon the surface, throughout the region of the Sierra. The same condition of things has been proved to exist in the central and eastern portion of the Cordilleras by the Fortieth Parallel and other Surveys which have more recently been extended over that region.

Again, we have to go but a short distance back in geological time when we find that a portion of the area embraced within the field of our observations was covered by snow and ice; so that we have offered to us, as occurring between epochs of great precipitation and of rapidly increasing desiccation, a period of ice extension, limited, it is true, to the higher portions of the most elevated ranges of the Cordilleras, but still general enough to imply the existence of some peculiar conditions at the time of its occurrence.

Thus, then, we find ourselves led, by the observation of phenomena connected with the geology and physical geography of the region west of the Rocky Mountains, to recognize at least three well-marked stages of climatic change; and the question which naturally presents itself in this connection is, whether a similar succession of events can be shown to have occurred in other regions, or generally throughout the world. If, as appears highly probable, this is the case, then we are led to inquire whether this sequence of changes is merely a series of disconnected events, in no way interdependent and not capable of being referred to any common cause; or whether, on the other hand, they are all linked together, as manifestations of one common cause, which has been acting through all geological time, and which will continue to act in the future. The inquiry thus hinted at forms the main object of the theoretical discussion which follows the presentation of facts occupying the first two chapters of the present volume; and the writer hopes that he has been able to throw some light on the character of the climatic changes which have taken place during the later geological times.

The scope of this discussion makes it necessary to introduce a considerable body of facts relating to the glacial and surface geology of regions not included within the Cordilleras. These topics must, of course, be treated in a very general way, for space would by no means permit of entering into minute details in regard to all the countries necessarily embraced within the field of so comprehensive an inquiry. To a very considerable extent the writer's own observations will be relied on as forming the basis of facts on which the discussion rests; but the endeavor will be made to give due credit for all the information obtained from other sources, and the reader will be directed where to find such additional material as may be accessible in the works of trustworthy authors, who have contributed matter of importance in the line of this inquiry.

In order to the better understanding of that which follows, it will be necessary to begin with some remarks on glaciers and ice-work in general. The scope of these remarks will be understood by those who read this chapter, and they will also see why what may, at first view, seem to be elementary considerations have been introduced into the present volume. The course here to be followed is particularly necessary in connection with Californian geology, because nowhere have such wild and absurd statements in regard to the work done by ice been published as in discussing the geological features of the Sierra Nevada. But it is true, also, that among geologists generally there has been, of late years, a decided tendency to exaggerate the importance of the work done by ice, and to leave out of consideration the preponderating influence of water in connection with so-called glacial phenomena. In the early stages of geological discussion the action of the ocean was the all-important factor: then ice had its day; and it is only quite recently that rain and rivers have begun to be recognized as being also extremely important agents in the formation, transportation, and deposition of detrital materials. The study of the gravels of the Sierra Nevada can hardly fail to convince the candid investigator that the work of rivers in that region has been of great geological importance. And it is confidently believed by the writer that the following chapter will fully illustrate and bear out the statement that, in the Sierra Nevada at least, ice has played but an extremely subordinate part as a geological agent, although there is no doubt that the great Californian range was once covered with grand glaciers, but little, if at all, inferior to those which now lend such a charm, both from a picturesque and geological point of view, to the Swiss Alps.

In endeavoring to give as clear an idea as possible of the character of the geological work which ice is now doing in various parts of the world, the use of some technical terms will be necessary. Most of those commonly employed in the text-books are, no doubt, familiar to the reader; but for a more precise understanding of the discussion which follows, it will be desirable to define and limit the use of certain terms of frequent occurrence, so that these may be employed without any danger of their use leading to erroneous ideas. The language is, it is true, deficient in words required to express what is often needed to be said in such a way as to include no theoretical views. Even with the aid of Latin words, the difficulty has not been entirely gotten over.

The simple word "gravel" has been employed in the gravel volume for the mixture of rounded pebbles and boulders with finer water-worn materials, with which the surface and hydraulic miner has to operate. As used throughout that work, it is of the nature of a miner's technical term, any unconsolidated detrital material washed for gold being called "gravel," while the more or less consolidated is usually distinguished as "cement." In the present volume the term "gravel" will be used with its ordinary signification, as meaning a mass of unconsolidated detrital material, made up chiefly of moderate-sized rounded and water-worn fragments of rock, which may be more or less mixed with sand, and according to its condition may be called coarse or fine gravel, sandy gravel, etc.

The term "diluvium," formerly much used for the superficial detrital deposits, has pretty much gone out of use, and been replaced by "drift." When, however, it is intended in the course of this chapter to refer to "drift," without any limiting of the meaning, or implication that it has been transported from any distance, the word "detritus" will be used, with the corresponding adjective "detrital." By detritus is understood any unconsolidated deposit of fragmental material, be the same coarse or fine, homogeneous or non-homogeneous, water-worn or angular, brought from a distance or derived from rocks close at hand. By the term "drift" will be designated such detrital deposits as have been moved to some distance from their original place of occurrence; and by "northern drift" is meant the detrital deposits of Northeastern America, which have been carried in a more or less southerly direction over a large area of country. The term "moraine" will be applied to such deposits as are known by their character and position to have been left in their present position by glaciers. Most if not all of the detrital material of Northeastern North America is destitute of any true morainic character. Under the idea that, notwithstanding this fact, it has had a glacial origin, and hence must once have had a structure analogous to that of true moraines, much of it has been designated as "modified drift"; by which term it is meant to be understood that its real origin has been to a certain extent masked by the action of water.

Detrital material arranged in long linear accumulations, somewhat resembling moraines, but partly stratified and differently situated with regard to the topography of the country from real moraines, are called sometimes by the Swedish term "ås" (plural åsar). The Scotch word "kame" is very closely analogous to ås in its meaning, and it has been used on this side of the Atlantic, as well as on the other. As defined by J. Geikie, it includes sands and gravels having a tendency to shape themselves into mounds and winding ridges, which give a hummocky and rapidly undulating outline to the ground.* The peculiarities of the åsar will be noticed somewhat in detail, when describing the glacial phenomena of Scandinavia.

The finer kinds of detrital material resulting from the wearing down of the rocky masses are variously designated, and usually by terms not liable to misconstruction. The quartzose portion of the rocks, especially the quartz itself, yields slowly to degradation, and is not so easily reduced to the finest condition; argillaceous rocks, on the other hand, readily allow themselves to be ground into the finest powder: hence we have sands, which are usually chiefly quartzose, and clays, or finely triturated argillaceous material. Of course sand and clay may become mechanically mixed with each other, and such mixtures are easily designated. The term "alluvium," with the corresponding adjective "alluvial," was originally used in opposition to diluvium and diluvial as implying a less turbulent origin, and as indicating the work of the present rivers, rather than of former larger and more general floods. When it is desired to define the different varieties of alluvial deposit and limit them by names, it is not found to be an easy matter, and certain terms have become quite generally adopted, but which are not capable of precise definition. It is not easy, for instance, to draw the line between "soil" and "loam," nor between "loam" and "loess," the latter being a term which has of late years come into quite general use, and including, as characteristic features of the material thus designated, fineness and uniformity of texture, and absence of any well-marked lines of stratification. Loess,

* J. Geikie, The Great Ice Age, p. 228.

then, is very nearly the equivalent of the English word loam; perhaps the best way to define it would be to say that loam when developed enough to become a formation of geological importance, and not a mere surface deposit, is loess.

The chief difficulty in investigating the work of glaciers lies in the fact that ice and water act together in almost all that is done in the way of bringing about geological changes in and near the glacier. In regard to a portion of this work it is impossible to say *ice* has done this, or *water* has done that; the two have acted together in bringing about the visible result. Another consideration to be kept in mind is this,—that the glacier is not a body of a certain fixed length. At the present time, and in former days, glaciers increase and diminish in length and thickness, sometimes rapidly, at other times slowly, and with repeated alternations of growth and diminution. In these changes part of the previous work of the glacier is obliterated, a part obscured, and, on the whole, the difficulty of distinguishing what is due exclusively to ice action is much increased.

The simplest function of the glacier is that of carrying detritus. The fragments detached from the walls of the valley through which the icy mass passes fall upon the surface of the glacier, and resting upon it move downwards until they reach its terminus. The characteristic features of the detrital material thus carried, and to which the name of "moraine" is applied, are its angularity, and the absence of any regularity in the way in which it lies, either while on the glacier itself or after having been delivered at the terminus. The material of the lateral moraine, or the detritus accumulated at the edges of the glacier, when dumped at the end of the route becomes the terminal moraine. A small portion of the detritus which falls on the glacier falls through crevices or gets otherwise entangled in the ice, and is lost to the moraine proper; but by far the larger portion reaches the end of its course very nearly in the same angular condition, and with the same heterogeneous character, which it had at the beginning of its journey. The form and size of the fragments of which the moraine is made up depend, of course, on the character of the rock formations over which the glacier moves. The pieces of rock rolled down from above will be transported with equal facility whether—as is sometimes the case—of enormous size, or only in the form of mere pebbles or sand. This is the criterion by which unaltered morainic detritus may be recognized, and by which it may be distinguished from any detrital deposits in the formation of which water has played a part.

The character and position of the terminal moraine will vary largely with the size of the glacier itself, and will also be greatly dependent on the circumstances of the advance and retreat of the glacial mass. If the glacier be very wide, and the lateral moraines small in proportion to the glacier itself, the terminal moraine will be almost exclusively limited to the two sides of the valley at the extremity of the glacier; if the latter be narrow and carrying a large quantity of detrital material, the lateral moraines will coalesce and form a single terminal one, barring the valley, except where the stream of water which must issue from the extremity of every glacier finds its way out. If the meteorological conditions are such that the glacier during a long period neither diminishes nor lengthens, the terminal moraine will become very large, and will gradually accumulate so as to cover a considerable portion of the ice itself, as is the case with some of the large glaciers of the Himalayan ranges. If, on the other hand, the glacier is, on the whole, decidedly shrinking, the terminal moraine will be less distinctly marked, because the detrital material is always being dumped a little farther up the valley.

When the glacier is advancing the phenomena become somewhat complicated. The ice, as it moves forward, shoves a portion of the detritus of previous morainic accumulations before it, and rises over another portion, which is then in a condition to be rapidly acted on by the glacier stream, and is soon converted into rounded boulders, with the synchronous formation of much gravel and sand of greater or less fineness.

The phenomena of the lateral and terminal moraines are quite simple as compared with those of the so-called "ground moraine,"—that is, the detrital material which lies under the glacier, and over which it moves. In regard to the importance of this material there is a great diversity of opinion. Before discussing the nature of the ground moraine, however, it will be necessary to say something about the glacier as an originator of detrital material, a subject in regard to which opinions differ most widely, some geologists looking upon glaciers as mighty erosive agents, and ascribing to them nearly all that has been done to give the earth's surface its present form, while others take quite an opposite view.

In regard to ordinary morainic material, there can be no doubt that the glacier is simply the carrier, and not the originator. As to what goes on above the surface of the ice there is no difficulty in getting at the facts; that which is done under its concealing cover is much less satisfactorily made out. And it must, in the first place, be called to mind that what takes place under the glacier is the joint result of ice and water action, and much of that which is done under the ice by water could be done, and is so, on an immense scale, equally well without the ice. There are, it is true, some geologists so prejudiced in favor of glacial erosion, if the expression may be allowed, as to claim that all fine detrital material is the result of ice-action. Some even go so far as to say that without glaciers we could have had no soil, an idea which leads to the inference that the entire earth must at some former time have been covered with ice, since there is no zone or region where deep deposits of finely comminuted material are not found. Indeed, the mass of facts which oppose any such theory as this is so great, that it is not necessary to occupy time in discussing the matter.

Ice, *per se*, has no erosive power. If the glacier were frozen to its bottom, and could then be made to move, it would, no doubt, tear away the projecting edges of the rock masses on which it was resting; but it is a perfectly well established fact that glaciers are not frozen to their beds. The glacier is snow which has been converted into ice by water, and without the latter the former cannot come into existence. The ice being permeated with water acts as a flexible body, taken as a whole, although in its parts it is not. By virtue of this condition it adapts itself to the channel through which it has to pass, bends around angular projections, rises over elevations, turns sharp corners, narrows and widens again and again, and comports itself, in short, just as we should expect a soft flexible body to do in passing over a hard inflexible one. The proof of this statement is to be found in the examination of any extensive mountain chain which has been formerly partly occupied by glaciers and from which they have since disappeared. No chain offers a better chance for an investigation of this kind than does the Sierra Nevada, as will be seen further on in this chapter. The recent shrinking of the Alpine glaciers has laid bare large surfaces which but a few years ago were covered with ice, and where the condition of the surface under the former glacier may be studied with the greatest facility. Nowhere, in any such region denuded of its former icy covering, will it be found that the glacier has had any power to cut through an obstacle so as to form a channel with vertical, or nearly vertical sides, as water often does. The whole form of the Alpine valleys is proof of this, for all will admit that if the ice which once filled many of these up to a higher level than it now does had such an erosive energy as is attributed to it by some geologists the section of those valleys must have been quite different from what it is at present. Had ice a peculiar erosive power, the bottom and the sides of the valleys through which former glaciers have passed would exhibit some peculiarities of form indicating that the work done below the level of the surface of the ice was of a different character from that done above that level. But, in point of fact, on examining any valley once partly filled with ice, it will be found that there is no such essential difference. No change of form can be observed at the former line of the ice. Aside from the morainic accumulations, there is nothing to prove the former existence of the glacier except the smoothed, polished, or rounded surfaces of the rocks, which have no more to do with the general outline of the cross-section of the valley than the marks of the cabinet-maker's sand-paper have to do with the shape and size of the article of furniture whose surface he has gone over with that material.

Admirable instances of the difference between the erosive action of water and that of ice may be seen in several of the valleys of the Bernina group, in the Upper Engadine. Near Pontresina, for instance, there is a rise in the bottom of the valley of between one and two hundred feet over which the Morteratsch glacier once passed without eroding it away. Since the glacier disappeared, the stream issuing from the ice, the end of which is now almost three miles above Pontresina, has cut a gorge through the elevation in question, which gives the stream a channel with nearly continuous grade, and hemmed in by almost vertical walls. The same thing may be seen in the Val de Fex, which leads down from the glacier of that name to the village of Sils, a few miles southwest of Pontresina. It is manifest, in both these cases, that the ice for a long time rose over an obstacle which was in its path, without the power of removing it; but that the water has quickly sawn itself a passage through the same, aided by the peculiar lithological character of the rock.

The most characteristic if not the most important work done by ice is that which it effects on its rocky bottom by means of the detrital material which has been carried down by water from the surface of the glacier. The icy mass moving over its bed smooths the edges of its inequalities by continually forcing fragments and particles of rock over them. Such smoothed surfaces are often found to be covered with fine lines or grooves, running, on the whole, parallel with the course of the glacier. These striated surfaces, which are so well known that they need not be described, are a peculiar result of the movement of the glacier, and their existence is in most instances accepted as positive proof of the former presence of ice.

It is a mistake, however, to suppose that striated surfaces cannot be produced by *dry rubbing*, or friction of surfaces against each other without the aid of ice or water. Every mining geologist knows from his daily experience that beautifully striated and polished surfaces have been produced in abundance by the sliding of portions of the vein material against its walls, and that this has often taken place where the amount of motion must have been very small, the immense pressure being sufficient to bring about the result, even when the distance over which the surfaces have moved cannot have exceeded a few inches. Excellent imitations of glacial striation are produced by the passage of heavy vehicles with locked wheels over rock surfaces. Pebbles also may be smoothed and striated by dry motion, provided they are fixed in their places while the motion takes place. Where heavy rock slides or avalanches have occurred, the bottom may occasionally be observed to be not only striated, but even deeply grooved. It is decidedly unjustifiable in the geologist to presume on the former existence of ice at any epoch or in any region from the occurrence of isolated smoothed and striated boulders or pebbles in the rock masses. Only by careful comparison of all the phenomena taken in their *ensemble*, over a considerable area of surface, can the former presence of ice be clearly established in a region where the present conditions are not such as themselves to throw light on the matter. For instance, the finding of an occasional striated boulder in a conglomerate of Devonian, Carboniferous, or Permian age would certainly not justify the geologist in inferring that glaciers must have been in existence at the time such rock was deposited.

As a consequence of long-continued crowding over the surface of the icy mass, which carries more or less detrital material imbedded in it, the projecting edges of the rocky strata gradually lose their sharpness, and become worn into those rounded forms to which the term *roches moutonnées* is commonly applied. This peculiar kind of surface is easily recognized by an experienced observer. But there are certain rocks which assume forms very closely imitating those produced by ice. Much granite, for instance, has a concentric structure, causing it to break under the influence of ordinary meteorological conditions into spherical forms, and to weather in masses with rounded surfaces, very much resembling the *roches moutonnées*. Want of knowledge of these facts has led to many mistakes of this kind, especially in the Sierra Nevada.

The conclusion to which the writer has arrived, after much examination of regions of present and former glaciation, is, that glacier ice has but little erosive power, and that the so-called "ground moraine" is an appendage of the glacier which is neither characteristic nor important. The present shrinking of the Alpine glaciers shows that there has been usually but little detrital material under them; and this has resulted not so much from the ice as from the water, which everywhere acts jointly with the ice in doing its work; indeed, the latter effects nothing absolutely characteristic, except the production of large areas of polished rock surfaces etched with fine parallel striations, a result which water alone is unable to bring about.

The action of icebergs in regard to striation of rock surfaces, and more especially the transportation of detrital material, is a subject of interest in this connection. From the very beginning of the discussions on these subjects there has been a marked amount of discrepancy of opinion in regard to the relative importance of glaciers and icebergs as geological agents, and as to the exact nature of the work done by each. Icebergs are born of glaciers,* so that the connection between the two is necessarily an intimate one, and the former may be said in their new condition to be simply floating glaciers. That the iceberg when detached from the glacier is often heavily loaded with detritus is a fact well known from abundant observations, and one which might be inferred without observation from the very nature of the case. That these floating detritus-carriers are able to transport their burdens to great distances, as they are moved by the winds and ocean currents into which they are borne, is also clearly understood. That such detritus, as accumulated along the route of the icebergs, will have a morainic character, —that is, will be angular and irregularly mixed,—is easily recognized. But no true moraine will be formed by icebergs, because they are not held to one exact course, as is the glacier enclosed between its rocky walls; while there must also be great irregularity in the distribution of the material left by icebergs, because they float with irregular course, according to the varying nature of the winds and currents, and because they are more or less rapidly melted, according to their size and their exposure to meteorological conditions which in their very nature are unstable.

The so-called "ice-foot" also acts, to a considerable extent, the part of the glacier, for it receives, when suitably situated, a considerable amount of falling detritus, and when loosened by the summer's heat floats off and bears this material away, iceberg fashion.

* The formation of an iceberg is familiarly known in Greenland as the "calving" of the glacier.

All floating masses of ice having fragments of rock frozen into them are able to striate and smooth the projecting surfaces of the rocks with which they may be brought in contact. The work which they thus do is closely analogous with that of the true glacier; but a comparison of all the conditions of any locality where such striations occur can hardly fail — in most cases at least — to settle the question of the nature of the agent involved.

The occurrence of work done by icebergs of course necessitates the former presence of the ocean, since the glacier must descend to the sea-level before it can give birth to an iceberg. That large bodies of fresh water might, however, to a certain extent play the part of the ocean as floaters of ice masses, can hardly be denied.

The abundance of lakes in certain regions which have been formerly covered with glaciers is looked upon by some geologists as a proof of the powerful erosive action of ice; and there are those who consider that all or nearly all lakes owe their origin to this cause. This seems to the writer an entire misconception of the nature of the work done by glacial agencies, and in support of this opinion the following considerations are offered. In the first place, however, it may be mentioned that there is one class of lakes in regard to whose glacial origin there can be no mistake. These are the so-called "moraine lakes," or collections of water formed behind a terminal moraine, left on the retreat of the glacier, and barring the valley more or less perfectly. The tendency of the streams issuing from such lakes is to wear away the opposing detrital mass, and thus to allow the superfluous water to escape; hence moraine lakes usually disappear in time, after the glacier has retreated sufficiently far, or disappeared altogether.

The existence of lakes depends, in most cases, on a somewhat complex set of causes. The principal conditions influencing their formation are such as are connected with the orography and the climatology of the region where they occur; but the nature of the rocks also plays an important part in their formation. If the orographic conditions are favorable, and the rainfall is not overbalanced by the evaporation, lakes will occur in greater or less abundance, and of greater and smaller size, in strict accordance with the character of the topography of the locality. Central Africa is an excellent illustration of the rationale of the formation of large lakes in a region of excessive rainfall, favored by suitable orographic conditions. The number of those great bodies of water is not yet known, nor have those which are known been much explored; but it is clear that within an area occupying a length of over fifteen degrees north and south, and a nearly equal breadth east and west, within the tropics, there are many lakes of great size, at an elevation of 3,000 feet and over above the sea-level. The region is one of great precipitation, and the orographic structure of the continental mass is eminently favorable to the formation of lakes, it being an elevated and comparatively level plateau surrounded by a rim of mountains. But there is still another reason for the existence of these great bodies of water. The rock is largely granitic, or crystalline in texture, not taking up a large percentage of the rainfall, but being almost impermeable. Most of these lakes are, in all probability, shallow; and their area is known to be quite variable, their dimensions changing with the season and with the succession of seasons.

Turning to equatorial South America, we find a complete contrast to the conditions just noticed as occurring in Central Africa with regard to the existence of lakes. Equatorial South America is drained by a large river,—the largest one in the world,—and so thoroughly drained that there are no important lakes at all in the whole of its basin, and but few small ones, except such as have a "bayou" character, and are evidently formed by the constant shifting of the channel naturally connected with the flow of a mighty river, with immense tributaries, subject to periodical inundations, through an almost level region. Of such lakes there are doubtless an abundance, but they are too small to be exhibited on our ordinary geographical maps, and their origin cannot be for a moment misunderstood. The orographic cause of this condition of things, offering such a contrast with the lake features of Central Africa, becomes evident on an examination of the structure of the region. While in Africa there is a rim all around the table-land, or elevated basin forming the interior of that continent, there is in South America no eastern raised border; but, on the other hand, a gradual inclination of the surface from the crest of the Andes to the Atlantic. Besides, the rocks over by far the larger part of the basin of the Amazons are of a kind easily retaining large quantities of water, and not granitic or crystalline.

There is probably hardly a single geologist among those most inclined to magnify the work of ice who would ascribe a glacial origin to the lakes of Central Africa, lying as they do within the tropics; but there are other lacustrine districts in the temperate zones in regard to which there would be less unanimity of opinion.

There are two especially interesting and important lake regions, besides that of Central Africa, to which allusion has already been made: one of these is in North America, the other in Europe. The former is a region of both great and small lakes; the latter of small ones exclusively. The North American lake system is the most extensive one in the world at the present time, although it may possibly have been surpassed, at a not very remote geological epoch, by that of Central Asia.

The geographical position of the region of country occupied by the great system of North American lakes is pretty well known, especially in its southern portion, although there is no map on which anything like the entire number of these bodies of water is shown; while for most, even of the largest, at best but a rough approximation to their outlines can be given. It may be well, therefore, to call the attention of the reader to the fact that, all along a line stretching in a northwesterly direction from Lake Superior to the Arctic Ocean, there are not only numerous, but almost innumerable, bodies of water, several of which are but little, if at all, inferior in size to even the largest of our so-called "Great Lakes." The number of lakes in this region is quite unknown; but a belt of country 2,000 miles long and fully 500 wide is a labyrinth of them, and they are of all dimensions, from mere ponds to bodies of water hundreds of miles in circumference. So too in the opposite direction, or along the range of the Laurentian Mountains, northeasterly from Lake Huron towards Labrador, there are unnumbered expanses of fresh water, mostly of moderate size compared with the Great Lakes, but many of them having a considerable area. These Canadian lakes have not yet been accurately mapped; but more than a thousand of them had, some fifteen years ago, been more or less explored by the Geological Survey. In fact, the whole region northwest of the St. Lawrence, as far as Hudson's Bay, is covered with lakes and lake-like expansions of the rivers, so that there is free access by canoe to every part of the country, with occasional portages, or "carries," around the rapids in the rivers.

In this lake region may be included a large part of Maine and the northern portion of New Hampshire, as well as of Vermont and Northeastern New York.

In striking contrast with what has been stated above, we find the region immediately south of the Great Lakes to be one almost entirely destitute of lakes. Everywhere, from the water-shed separating the waters flowing into the Susquehanna and Ohio from those running northwards, as far south as the Gulf of Mexico, there is an almost entire absence of lakes; indeed, it would be hardly possible to imagine a greater contrast, in this respect, between two adjacent regions of country, and it will be desirable to inquire into the causes which have brought about this curious condition of things.

The causes which have produced this extraordinary complex of lakes in the northeastern region of North America are by no means simple. They are partly orographic and geological, partly climatological. Ice has also played a part in this work, although, as it appears to the writer, quite a subordinate one.

The orographic element in the work will be easily recognized from an inspection of a good map of North America. If two parallel lines be drawn, about 500 miles apart, one touching Georgian Bay of Lake Huron, the other the southwest corner of Lake Michigan, and prolonged in a northwesterly direction to the Arctic Ocean, the great series of lakes belonging to the system will be found lying within the belt of country thus limited. These lines, however, are parallel with the general trend of the adjacent portion of the Cordilleras, showing at once the orographic character of the belt of depressions. Furthermore, the direction of the axes of the larger lakes within this area is usually at right angles to the line of trend mentioned, which fact is another important guide to the character of the forces by which these depressions have been produced. Again, the connection of the orographic character of the lake belt in question with its geological position is most marked. This great chain of lakes, as will be apparent whenever a good geological map of the region shall have been published, lies on and in the neighborhood of the belt separating the modern geological formations which belong to the Rocky Mountain uplift, from the Azoic or older crystalline schists and granites, forming the mass of the Laurentian Range. This belt is made up of Palæozoic rocks, and it is in these that the large lakes are chiefly developed. The moment that we pass from the older rocks on to the more recent, in going westward, we at once leave the lacustrine region behind. A portion of this belt is depressed beneath the sea-level even, Lake Superior, the surface of which is 609 feet above that line, being in places over 1,000 feet in depth. This lake occupies a synclinal depression of the Palæozoic rocks, just along the edge of the Azoic Series.*

Lake Huron is similarly situated, its northern edge abutting against the older crystalline rocks. In fact, all the Great Lakes, including those of British America, from Ontario around the great sweep of 3,000 miles to the Arctic Ocean, are in a similar geological position, occupying a depressed

* As long since shown by Foster and Whitney. See Report on the Geology of Lake Superior, Part II. p. 117.

area along the base of the Azoic nucleus of Northeastern America, an area which has not partaken of the uplift by which the Appalachian chain has been formed, or of that much more recent one which has given rise to the system of the Cordilleras. These lakes are all either entirely included within the Palæozoic, or else partly in that formation and partly in the Azoic, and in no case do they extend into the more recent groups of strata which are found, on going south or west from the older rocks, to overlap these latter formations. The orographic character of these large bodies of water is therefore the most marked feature of their occurrence, and there is nothing about them which renders it necessary, or even possible, to refer their origin to glacial erosion; there is nothing in their position or the direction of their axes which in any way lends countenance to the idea of their basins having been scooped out by the action of ice.

Climatological causes act together with orographic ones in the formation and maintenance of the lakes in question. The depressions of the surface are kept filled by the annual precipitation, which more than overcomes the evaporation; for the region is one of considerable rainfall, and of pretty high northern latitude. The surplus water is chiefly carried off by two mighty rivers, the St. Lawrence and the Mackenzie, of which rivers all the Great Lakes — with the exception of Winnipeg and Winnepegosis — are expansions.

Very different from this is the condition of things in the so-called "Great Basin." Here was once a region of large lakes, many in number, and some of them little, if at all, inferior in size to the Great Lakes themselves. But the climate has changed; the lakes have shrunk up and nearly or quite disappeared, and in most cases there is nothing left but old lake bottoms, covered with alkaline or saline deposits in the dry season, and with mud or shallow water in the wet. No one could by any possibility assign any other than an orographic origin to these lake-basins; that they are not now filled with water is due to climatological causes, to the nature of which reference will be made further on.

That lakes of large area are essentially nothing more than portions of the earth's surface depressed by crust movements below the general level of drainage, and kept full and running over by the excess of precipitation over evaporation, seems to be perfectly clear; to admit that they are the result of erosive action would require us also to believe that large, nearly closed seas, like Hudson's Bay and the Mediterranean, are areas of erosion; and it would be only a logical sequence of ideas to declare the ocean itself to have been washed out from the land, and the continental masses built up from the material thus eroded.

The origin of the smaller lakes with which certain areas of the earth's surface are profusely dotted is a problem much more difficult than the one just discussed. As already mentioned, there are two regions in which small lakes occur in the greatest abundance. One is the country north of the St. Lawrence, a district of both large and small bodies of water; the other, Finland. Such small lakes are almost invariably quite shallow; it can only be a very peculiar and highly exceptional condition of things which can produce a very deep lake of small area. The essential facts influencing the formation of small lakes are, a nearly level surface of the region in which they occur, and an underlying rock formation impervious to water.

Both Finland and the Canada lake region are underlain by crystalline rocks, which are almost impermeable. If we follow on the map the outlines of the district in Northeastern America where lakes abound, we find that these are left behind as soon as we pass out of the domain of the crystalline or metamorphic rocks into that of stratified and permeable formations. For instance, the contrast between the frequency of lakes in Northern Wisconsin, a region of Azoic rocks, and the central and southern portions of the same State, where stratified sandstones are the predominating formation, is most striking. The peninsula of Southern Michigan, and that triangular portion of Canada lying between Lakes Erie and Huron, offer similar contrasts when compared with adjacent regions of impermeable rocks. Minnesota and the adjacent Territory of Dakota also afford an excellent illustration of the limitation of lakes to regions of rocks whose texture is impervious to water.

That level regions of country should be more favorable to the development of small lake basins than the flanks of mountains, is easily understood. A rapid descent gives the streams great erosive power, and they are enabled to wear away their beds so as to drain depressions which would otherwise be partly or wholly filled with water. Given a level region underlain by impervious rocks, the precipitation being moderately in excess of the evaporation, and it is manifest that the water must stand upon the surface over areas of greater or less magnitude, unless there can be some reason assigned why that surface should be absolutely level. Deposits laid down under the ocean are more likely to be evenly distributed than those which result from fluvial action, because the former are the result of agencies working on a grand scale, while the latter are more local in character. Hence, when such submarine deposits are raised above the surface, and in that elevation have been not at all or only very slightly disturbed, the drainage of the uplifted region will be effected simply by rivers, there being few depressions to be filled with the excess of precipitation and thus to become lakes. Highly metamorphic rocks, on the other hand, are not only by their nature impervious to water, but they must have been left, after passing through the various stages of chemical change and orographic displacement, with an uneven surface, suited to give rise to collections of standing water. This result, under suitable climatological conditions, cannot fail to take place, unless the irregular surface is afterwards subjected to some erosive agency which smooths it over and reduces it to one uniform level. Erosion of this kind can, however, but rarely take place, for the ordinary denuding agents are quite as likely to deepen the previously existing depressions as to obliterate them. A level surface may indeed be produced in such cases by the entire surface becoming uniformly covered with detrital material; but this can only be effected by a submergence of the region beneath the sea, during a long period and under favorable conditions.

Keeping the above considerations in view, it will be evident why regions like Canada and Finland are covered with a network of small lakes. The countries in question are underlain by impermeable rocks, which have during an immense period been subjected to subaerial erosion. The overlying detritus is usually quite thin, and only here and there accumulated in heavy masses. It consists largely of gravel, but has enough clayey material connected with it to favor the formation of lakes and ponds. Water has a tendency to accumulate in the depressions of the solid rock, and this tendency is further aided by the peculiar manner in which the eroded materials have been scattered over the surface. The impervious character of the underlying rock, the thinness and irregular distribution of the overlying detritus, and the general uniformity of level of the region, — these are the agencies which have given rise to the multiplicity of lakes in the countries in question.

Thus we see why, as soon as we leave the region of crystalline rocks, either in Northwestern Russia or Northeastern America, we leave the lakes behind us, as already indicated. That glacial erosion is not the cause of the sudden change in this respect, is shown clearly enough by the fact that we pass at once, in the midst of an area formerly covered with ice, as would be admitted by all glacialists, from a region of lakes into one totally destitute of them, the underlying rocks having changed their character, while the proofs of the former presence of ice remain the same.

Illustrations of the occurrence of lakes of various origin on the Pacific Coast will be given in describing the glacial features and surface geology of that region. Intimately related to the topic just discussed is the subject of the formation of fiords, to which in this connection a few pages may be devoted.

It will appear evident, from what has been said in the gravel volume in regard to the depth and number of the cañons on the west slope of the Sierra, that if the land were submerged or the sea-level raised a few hundred feet, not only would the Sacramento and San Joaquin Valley be covered with water, but the coast-line on the eastern side of this large inland sea would have an extremely irregular outline, being deeply indented in many places, these indentations having very precipitous sides, and offering in every respect a striking analogy with the so-called fiords of the Scandinavian Peninsula. Looking along the present coast of the Pacific side of North America, we find a line remarkably free from indentations until we reach the vicinity of Vancouver Island, when we come suddenly upon a region of deep inlets and numerous outlying islands of large and small size, very incompletely represented, however, on our ordinary maps. Good harbors are as abundant in this region as they are few and far between to the south. Turning our attention to other parts of the world, we find the same remarkable difference between the coast-lines of different regions. South America strikes us at once as being extremely deficient in indentations affording good harbors, from its northern extremity almost to its southern. Africa wants them almost entirely in every portion of its outline. This peculiar frequency of fiords or deep indentations of the coast has been the subject of considerable discussion; yet, as there are difficulties in regard to their origin and mode of occurrence which have not been removed, it will perhaps be worth while to endeavor to throw some additional light on the subject.

The mere recapitulation of the regions of fiords and deeply indented coasts will show at once that they are almost exclusively confined to high latitudes, both northern and southern. That they are much more extensively developed north of the equator than south, is very naturally accounted for by the fact that there is so little land in high latitudes in the southern hemisphere.

Only the southern end of South America and the west side of the southern extremity of New Zealand on that side of the equator can be included in the list of typical fiord regions. The Atlantic coast-line of the Scandinavian Peninsula, the west coast of Greenland, and perhaps also its east coast, — of which little is known, owing to its inaccessibility, — the northwest coast of North America, above Vancouver Island, — these are typical fiord regions. In lower latitudes, the east side of the Adriatic Sea, especially its northern portion, as well as the Grecian Peninsula, also belongs decidedly to fiord regions, but does not exhibit these indentations on as grand a scale as the first mentioned.

The first thing which may be noticed in regard to indented coasts is, that they are usually coasts rising precipitously from the water, or such as are bordered by mountains or the descending edges of high plateau regions. In fact, a mountainous background is an essential part of a true fiord coast. A glance at the maps will show this to be a fact. But it is not by any means every mountainous coast which abounds in fiords. For instance, the stretch of shore line from San Francisco south for several hundred miles is bordered by a high mountain chain, but possesses hardly a single indentation, a want most seriously felt in its relations to commerce. The whole coast of South America is another excellent illustration of this; it is, however, not to be denied that the Andes do not rise immediately from the coast, although they may seem to do so to those looking at the ordinary small-scale maps.

The evident reason for the association of mountainous coasts with fiords is, that these peculiar indentations represent an amount of erosive action which can only be had in a high mountain range. Two things are required for the erosion of these deep gorges which under suitable conditions become fiords. These are: first, a large precipitation, or a great deal of material with which to do the work; and, second, a rapid fall of the surface, which gives the power by which this material acts. All great mountain chains have their sides deeply furrowed with steep valleys, gorges, or cañons. Let the Alps, or the Himalayas, or any other great range, be sunk to a suitable depth beneath the water, and the result will be that the central dominant range will project above the surface of the water with an irregular and deeply indented coast-line, while there will be occasional, and in some cases numerous, groups of islands in the vicinity of such a coast. Let any one study the Norwegian coast, for instance, and he will see at once that what are now fiords would become mountain valleys if the region were elevated so as to bring the bottom of these fiords above the surface of the water, while certain points higher than the adjacent surface, but now deep beneath the water, would appear as islands. Hence almost all fiord coasts are accompanied by outlying fragments of land of greater or less size, as is well illustrated on the Norwegian coast; and also, in a higher degree, by the shores of British Columbia, from Vancouver Island north.

In considering the nature and origin of fiords, we are led irresistibly to the conclusion long since enunciated by Professor Dana, namely, that fiords are evidences of subsidence; the regions where they occur are those where a high mountain range has become partially submerged, so that the bottoms of the deep valleys of erosion are now occupied by the sea.

It has been claimed by some writers on this subject that the occurrence of fiords in high latitudes is proof that the excavation and erosion which they indicate to have taken place has been the work of ice. All that we have observed, however, with regard to the amount of erosion which ice is capable of effecting, leads us to infer that glaciers have had little to do with the matter; unless it be that, to a certain extent, the filling by ice of valleys already formed has prevented their being afterwards occupied by the detrital materials which would necessarily accumulate in a mountain valley where the slope was insufficient to give to running water the power to remove such detritus, or where, from climatological changes, the amount of precipitation has diminished, and thus the erosive action decreased, so that the gorges could no longer be swept clean of the detritus carried down into them from their borders of more or less precipitous rocks.

The fact that the fiords are chiefly on the western side of the continents has been insisted on as connecting their origin with the occurrence of areas of great precipitation, the sides of mountain ranges in the extra-tropical latitudes which are exposed to the return trade-winds being likely to receive a much greater rain and snow fall than the opposite or eastern flanks of the same chains. The abundant precipitation in the form of rain giving rise to the deep gorges on the mountain sides which are afterwards to be converted into fiords by the sinking of the region, the continuance of the same increased precipitation in the form of snow, under those changed climatic conditions which will be explained further on, causes these precipitous valleys to become filled with ice, which carries the detrital material away on its surface, and deposits it sometimes at a great distance from its source, as the icebergs formed from glaciers coming down to the sea on the west coast of Greenland are now doing on a grand scale. All the conditions required for the formation of fiords are illustrated by the phenomena displayed on the coast of the Scandinavian Peninsula, as will be noticed further on.

The facts, then, connected with the occurrence of deeply indented coasts and fiords are briefly as follows: A coast-line may be very irregular and deeply indented where the adjacent land is low and level, as, for instance, the east side of Denmark. This is simply the result of the wearing away of the easily yielding land by the ocean. Such coasts are very different in character from those of typical fiord regions. These must be connected with high mountain ranges, and the fiords are the result of erosion of their sides by water. Hence they occur chiefly in regions of large precipitation. But the gorges thus eroded do not become fiords until subsidence of the range has brought them down into such a position that the water of the ocean can enter and partly fill the precipitous valleys which have thus been created. Should the range remain stationary in elevation after the decline of the period of greatest precipitation, the eroded valleys would gradually become filled with detrital material, unless protected from this by becoming partly filled with ice at a later period, in consequence of a change of climate, the nature and cause of which will be explained further on.

A depression of the crust appears, for some reason not yet explained, to have been going on during the most recent geological ages in high northern latitudes. Hence we find that peculiar sequence of conditions necessary for originating truly typical fiord-coasts to have occurred only in a few regions, although approximations to these peculiar indentations are found in all latitudes and in various countries.

It must be admitted, however, that erosion has not done all the work of forming the precipitous valleys which have become converted into fiords. The ranges in which these grand gorges and transverse cuts occur have been elevated by internal forces; it is highly improbable that the great masses of rock were brought into their final position with smooth, unbroken surfaces. On the contrary, the uplifted crust must, in many places at least, have been broken, shattered, and left with the most irregular outlines. The features of the country have thus been rough-hewn, and the work of water has been carried on in strict subordination to that previously effected by mightier and deeper-seated causes. Such is the opinion of the present writer, although he is well aware that, as already suggested, there are other geologists who think very differently, and who, in point of fact, consider that nearly all the sculpturing of the earth's surface has been done by the agency of ice. The subject will, it is thought, receive some light from what has been stated in the gravel volume with regard to facts observed in the Sierra Nevada and elsewhere.

SECTION II. — *Former Glaciation of the Sierra Nevada, of the Pacific Coast, and of the Cordilleras in general.*

Some account may now be given of the facts which have been collected during the progress of the Geological Survey of California in reference to the former extension of glaciers over portions of the Sierra Range, and to these will be added such information as is in our possession, obtained from various sources, about the development of the ice-period in regions adjacent to the Pacific Coast, and in the Cordilleras generally. Brief statements of the facts observed in the Sierra Nevada have already been published in the Geology of California, Vol. I.; and the object at present is to put these and more recent observations into a connected form, so as to open the way for a discussion as to their importance, both in reference to the distribution of surface detritus in the Sierra, and to the theories of former ice extension generally.

The first fact to be noticed is the great ease with which the evidences of former glaciation in the Sierra Nevada are obtained. There is nothing doubtful about the matter; once one enters upon a formerly glaciated region there is no possibility of mistaking the origin of the phenomena presented to view. Polished and scratched surfaces, smoothed and rounded ledges (*roches moutonnées*), transported boulders, and, above all, moraines of various kinds, are all recognized with the greatest ease by the observer, making a combination of occurrences which no one familiar with glacier regions could for a moment hesitate to refer to their true cause. The difficulty has been, however, that a good deal has been published by various persons who were quite unacquainted with glacial work, and who indeed in some cases had not had the advantage of a previous training as observers in any department of geology; and these writers have brought confusion into the subject by referring many phenomena to the effects of ice where there was by no means any sufficient authority for such reference. Some have even gone so far as to sprinkle living glaciers all over the Sierra, and others have ascribed to ice the principal share, or even the exclusive agency, in forming and fashioning the grand peaks and domes of the Sierra. There are few parts of the world where the dynamical agencies of ice in past times can be more conveniently and profitably studied than in the region in question; but it is very desirable that such study should not be entered upon with preconceived theories, and that it should have been either preceded or at least afterwards supplemented by analogous studies in other regions of present extensive glaciation, like Switzerland or Norway. Such study on the part of some of those who have given their opinions with the greatest fluency in reference to supposed glacier work on the Pacific coast would perhaps have made these writers a little more cautious in advancing their crude and often utterly absurd theories.

The reason of the very plain and obvious nature of the former glacier work in the Sierra is due in large part to the very recent date of its occurrence; and this fact links itself unmistakably with another important one, namely, that the glaciation of the range is absolutely and entirely in harmony with its present topography. The whole body of facts collected by the Geological Survey shows most clearly that there has been no essential change in altitude of the formerly glaciated regions since the ice disappeared; and, still further, that all the features of the surface — valley, gorge, cañon, cliff, dome, ridge — remain just as they were when the climatic conditions changed so as to bring about the shrinkage and final obliteration of the once extensive ice-masses. It is even clear that the volcanic fires of the Sierra were entirely spent before the glaciation of the range took place. In short, the ice-period in California was the most recent of all the geological phenomena there exhibited; and, as will be clearly shown, it cannot be considered to have been removed by any but a very moderate amount of time from the actual present.

In commencing a rapid review of the former distribution of glaciers on the Sierra, we may begin by referring to the well-known fact, that the range sinks in general elevation as we proceed northward from the culminating region in lat. 36° 30′; southward from this the range also breaks off quite abruptly. Glacial phenomena are therefore cut off altogether, to the south of 36°, by the rapid decrease of the range in altitude, combined with constant diminution in latitude. To the north the falling off in altitude is partly compensated by the more northerly position, so that we have a belt along the Sierra of from three to four degrees in width, where the phenomena of ancient glaciation are chiefly displayed.

The most striking feature in this glaciated region is, that the extent of the former glaciers was strictly in harmony with that of the elevated region which was the field of supply for the ice-stream. A large area, at a sufficiently high elevation, where the snow could collect and become consolidated into ice, gave birth to a proportionately large glacier, just as now in the Alps the Aletsch and the Gorner glaciers, and the Mer de Glace, have at their heads the largest amphitheatres, or *cirques*, and are consequently the longest and best developed glaciers of the Swiss mountains.

Before proceeding to a description of the phenomena of extinct glaciation in the Sierra Nevada, it is desirable to say something in regard to the present distribution of snow and ice in that range, and in the Cordilleras generally. And in the first place it may be stated that there are no glaciers at all in the Sierra Nevada proper, and none in the Great Basin or Rocky Mountain ranges, at least south of the parallel of 42°. With the exception of some recent discoveries said to have been made in 1878, in the Wind River Range (about lat. 43°), by the U. S. geological surveying parties, of which no definite account seems as yet to have been published,* it may be stated that there are no proper glaciers anywhere within the limits of the United States (Alaska not included), except around the great isolated volcanic cones of the Pacific Coast. There are certainly none in the highest portions of the Sierra Nevada or the Rocky Mountains, these most elevated regions having been sufficiently explored to ascertain that fact. The Wind River Range and the region adjacent to it is considerably inferior in height to the peaks and valleys around the South Park and the upper part of the Arkansas River; but the difference of four degrees in latitude more than counterbalances the difference of elevation, as respects the conditions necessary for the formation of glaciers.

The precipitation on the flanks of the Sierra Nevada is much larger on the western slope than on the eastern, and it undoubtedly is considerably greater near the summit than lower down on the slope. Unfortunately, statistics are almost entirely wanting. It is well known, however, that the precipitation is nearly all in the form of snow along the crest of the Sierra, and that it falls in the winter months almost exclusively. Near the summit of the range there is, in the summer, an occasional heavy thunder-storm, attended with a

* Nothing seems yet to have been published in regard to these glaciers, beyond the statement, in the Preliminary Report of the Field Work of the U. S. Geological and Geographical Survey for the Season of 1878, that "three genuine glaciers were discovered on the east base of Wind River and Fremont Peaks." Dr. Hayden informed the writer that the largest of these glaciers might be perhaps a mile in length.

fall of rain, the quantity of which may in some rare instances be quite large. Such events are not common enough to be allowed any weight as elements in the climate. In the central portion of California snow only rarely falls in localities lower than 2,000 or 2,500 feet above the sea-level. There are sometimes several years in succession when the portions of the Coast Ranges in sight from the city of San Francisco, and from 3,000 to 4,000 feet in altitude, are never whitened with snow; and when this does occur, it is rarely for more than a few days at a time. Yet there have been years when quite heavy falls of snow have taken place, even in the valleys, in the immediate vicinity of that city.

In the Sierra Nevada, although the different years are quite variable with respect to the snow-fall, it does not often happen that it is not large in the higher portions of the range. In some seasons it becomes enormous, amounting, as is stated on good authority, to more than sixty feet. Of course, even in ordinary years, the accumulations of snow in the deep cañons, and in other sheltered places into which it is driven by the wind, are sometimes of great thickness. As a general thing this snow disappears very quietly, in large part by evaporation, and the rivers are not so much swollen by its melting as would be expected. It is only when a heavy general snow-fall is succeeded by a warm rain, occurring over a wide area and extending to considerable altitude, that such heavy freshets take place as that of the winter of 1861–62, when a considerable portion of the Sacramento Valley was deeply flooded with water. During ordinary years the snow appears, as the range is seen from a distance, to have pretty much disappeared by May or June. But the crest of the Sierra is never entirely denuded of its snowy covering, although at the end of a long and hot summer, following an unusually dry winter, it may seem to be so. In the sheltered nooks and deep crevices, especially on the north side of the higher peaks, patches of considerable size will always be found. This is especially true for the higher portion of the range, as far north as the north end of Lake Tahoe. Beyond this, to Lassen's Peak, where the highest passes are not much over 7,000 feet, and the peaks between 8,000 and 9,000 in height, there is ordinarily but very little snow left at the end of the summer. In Plumas County there were in 1866 only one or two of the highest points on which snow remained through the entire summer, all having disappeared except a few small patches on the northern slopes of the most elevated peaks. On Lassen's Peak, however, quite large bodies remain permanently; or at least have always been there when this mountain, which is about 10,600 feet high, has been seen by the Survey. These snow spots, the lowest of which lies about 2,000 feet below the summit, have appeared of about the same size and form when seen in different years during the summer months.

From Lassen's Peak as far as Mount Shasta there is no permanent accumulation of snow; but on the last-named grand volcanic cone, which is over 14,000 feet high, there seem to be always large bodies lasting throughout the summer, and extending down to points 6,000 or 7,000 feet below the summit. In September, 1862, when the quantity for that year was at a minimum, the cone of Shasta looked dazzlingly white at a distance, as seen from the south. On approaching the mountain to within a few miles, the ridges and crests between the ravines furrowing its sides were found to be bare; and on actually climbing to its summit it seemed difficult to understand how, when so much of the upper part of the cone was uncovered, it could appear, fifty miles off, to be one unbroken mass of snow. This was the year following a winter of extreme precipitation; and, judging from photographs taken by Mr. Watkins in 1870, and from information received at various times,* there have been seasons when there was much less snow on this mountain than there was when we climbed it.

At the time Mount Shasta was ascended by the writer, in company with a party of the State Geological Survey (September, 1862), nothing was seen or known of the existence of any glaciers on or near this peak. The only approach to ice observed was near the summit, where a large, nearly level area was found to be covered with snow, described in the account of the trip afterwards published as being "almost icy in texture," and intersected by crevices from two to three feet deep.† This might perhaps pass as *névé*, but could not by any possibility have been called a glacier. This ascent was made on the southwestern side of the mountain. Later in the season Messrs. Brewer and King, of the Geological Survey, continued the reconnaissance of Shasta by a journey along its northern base; but still no glaciers were noticed. Some years later, in 1870, Mr. King, in making a detailed examination of the mountain, discovered several large glaciers, of which only a preliminary account has been published.‡

* Especially from Mr. J. H. Sisson, mentioned in Geology of California, Vol. I. p. 332, as residing near the base of Shasta, and as having frequently acted as a guide to its summit.

† See Geology of California, Vol. I. p. 340.

‡ A full report of these explorations of the Pacific Coast volcanoes by Messrs. King, Hague, Emmons, and Wilson has never been published. Mr. King gave a short account of his investigations around Shasta in an article in

It appears that circumstances were very unfavorable for the finding of these glaciers at the time when the party under the direction of the writer ascended Mount Shasta. They were probably deeply covered with snow; but, even if they had not been, they might not have been observed, for soon after reaching the summit, and while attending to the barometrical observations, clouds gathered so as entirely to obstruct the view down the slopes of the mountain. There being no glaciers on the south side of the cone, it was not supposed likely that there would be any on the other. According to Mr. King's observations, however, an east and west line divides the mountain into glacier-bearing and non-glacier-bearing halves. At the time of his visit the snow masses were less than had ever been known before; from the earliest settlement of Strawberry and Shasta Valleys there had never been such a complete denudation of the mountain. The photographs taken by Mr. Watkins at that time show the southern side of the cone to be almost entirely bare; and it was from the southwest that our party, towards the close of the season of 1862, ascended over a snow-slope at least seven miles in length.

Mr. King describes three principal glaciers, the largest about four and a half miles in length and two or three miles wide. He remarks as follows: "We explored one after another all the cañons, which, approximately following the radius of the cone, are carved to a greater or less depth with the lava-flows. From the secondary cone around to the eastern side of the main mass are only occasional fields of snow and ice, — bodies of a thousand or two feet long, usually quite narrow, and lying on the more shaded sides of the ravines. In nature and texture they are quite similar to the true glacier ice, possessing in all cases planes of stratification which indicate the pressure of the formerly overlying masses." The principal glacier is on the north slope of the mountain. Of it Mr. King remarks as follows: "Receiving the snows of the entire north slope of the cone, it falls in a great field, covering the slope of the mountain for a breadth of about three or four miles, reaching down the cañons between four and five miles, its lower edge dividing into a number of lesser ice-streams, which occupy the beds of the cañons. This mass is sufficiently large to partake of the convexity of the cone, and judging from the depths of the cañons upon the south

the American Journal of Science, for March, 1871 (Third Series, Vol. I. p. 157), and Mr. Emmons read a paper entitled "The Volcanoes of the United States Pacific Coast," before the American Geographical Society at its meeting of March 13, 1877. This last-named paper is chiefly devoted to an account of the ascent of Mount Rainier by himself and Mr. A. D. Wilson.

and southeast slopes of the mountain, the thickness cannot be less than from 1,800 to 2,500 feet. It is crevassed in a series of immense chasms, some of them 2,000 feet long by thirty and even fifty feet wide. In one or two places the whole surface is broken with concentric systems of fissures, and these are invaded with a set of radial breaks which shatter the ice into a confusion of immense blocks. The region of the terminal moraines is quite unlike that of the Alps, a large portion of the glacier itself being covered by loads of angular débris. The whole north face of the mountain is one great body of ice, interrupted by a few sharp lava ridges which project above its general level. The veins of blue ice, the planes of stratification, were distinctly observed, but neither *moulins* nor regular dirt-bands are present. Numerous streams, however, flow over the surface of the ice, but they happen to pour into crevasses which are at present quite wide."

No statement is made of the height above the sea-level to which the ice descends at its lowest point. Judging from the appearance of the cone as seen from the north, and from the photographs, it may be about 10,000 feet. The different views, taken by Mr. Watkins, give the impression that a considerably less area of the surface of the cone is occupied by ice than is described by Mr. King as being so covered. The fact that the débris extend over so much of the glacial surface is evidently to be explained by the almost stationary character of these glaciers. Hardly any snow or rain falls upon them during the summer, and by far the larger portion of that which descends in winter is evaporated without actual melting, owing to the intense dryness of the climate. That the climatological conditions all through California are peculiar, is well known, and these peculiarities extend even to the summit of Shasta, as is well illustrated by the fact that our party found on the summit pieces of paper on which the names of visitors had been recorded, in some instances several years before, and which remained perfectly unchanged by decay or discoloration. That the masses of ice should be limited to the northern side of the mountain is something which might be expected; for as the prevailing winds in summer came from the south and southwest, the moisture which they carried away would be most likely to be condensed in part, at least, in the eddy which would take place just at the passage from the warm over to the cold side of the descending slope, which remains during the warmer part of the day in shadow.

A careful examination of all the details of structure of these ice-masses, by some one who has had experience in similar work in the classic glacier regions of Europe, is much to be desired. It is quite likely that the Shasta glaciers are literally the remains of former more extensive glaciation; and that if it were possible for them to be entirely removed, they would not under the present climatological conditions be able to form again. Judging from what we know of the conditions necessary for the formation of glacier ice, and from the past history of the glaciation of the Sierra, it is not unlikely that at the bottoms of the deepest and most persistent snow accumulations on the flanks of that range *névé* or even ice may be found at times when, as in 1870, the occurrence of several especially dry seasons in succession has caused the snow to shrink to a minimum. In spite of the dryness of the atmosphere, some of the melting snow must sink down into the mass, and there are also occasional showers to moisten it, so that in the long run the formation of *névé* or even of ice itself may take place. In 1866, which was a year when there was less than the usual amount of snow in the Sierra, Messrs. King and Gardner, in the course of their explorations for the Geological Survey, discovered a bed of ice on the east slope of Mount Ritter, which was thus described in their notes: "In a deep *cul-de-sac*, which opens southeast on the east slope [of Mount Ritter], lies a bed of ice two hundred yards wide, and about half a mile long. It has moved down from the upper end of the gorge from thirty to fifty feet this year, leaving a deep gulf between the vertical stone wall and the ice." No such masses of ice were found by the writer or by any of his corps at any time, in the higher portions of the Sierra farther south; although such have been reported by others, but not by persons having had any previous experience in the investigation of glacial phenomena. It is doubtful whether these residual masses of ice can with propriety be called glaciers; they have no geological significance as such at the present time, however interesting they may be as possible relics of a once general glaciation of the highest part of the range.

The explorations of Messrs. A. Hague and Emmons on Mount Hood and Mount Rainier revealed the presence of large glaciers on those volcanic cones, as would be naturally expected from their great height and high northern latitude as compared with Mount Shasta. Mount Rainier is 3,000 feet higher than Hood, and almost two degrees farther north, besides being much larger in mass; its glacier system is therefore very much more extensive than that of the last-named cone. The largest described by Mr. Emmons is that which forms the head of White River, running north into Puget Sound. Of this glacier the greatest width on the steep slope of the mountain is said to be four or five miles, and its length scarcely less than ten.

Mount Baker, which is near the boundary line between the United States and British Columbia (latitude 49°), and which is 10,791 feet in height according to the measurements of the U. S. Coast Survey, is said to have large glaciers upon its flanks, as would be expected from its northerly position and proximity to the sea.* It has never been ascended by any one possessed of sufficient scientific knowledge to describe with accuracy the character and conditions of the ice-fields.

Farther north in British Columbia the absence of maps making any approach to accuracy, and of detailed geological explorations, make it impossible to give anything more than the most general statements in regard to the present glaciation of the Cordilleras in their extension north of latitude 49°. No active glaciers have been noticed on the eastern ranges, or the continuation of the Rocky Mountains proper, until some distance north of the boundary has been reached.

According to Dr. Hector, the geologist attached to the Palliser Expedition (1857–60), the mean altitude of the Rocky Mountains between latitudes 49° and 53° is about 12,000 feet above the sea; but there is a singular absence of marked peaks. The chain, according to the same authority, culminates in latitude 52°, where the mountains are very massive, and traversed by profound valleys, the highest offsets from which are occupied by glaciers. Considering the great elevation and high northern latitude of this portion of the range, it seems remarkable that so few glaciers should exist there. Mr. Selwyn, chief of the Canada Geological Survey, in his exploration of 1875, at the head of Peace River, still farther north, in latitude 56°, observed only patches of snow, sometimes of several acres in extent, but no glaciers or permanent snow peaks. The altitude of the point ascended by Mr. Selwyn, and from which, as he remarks, a perfect sea of Alpine peaks and ridges was visible, was only about 6,200 feet, a falling off in elevation of the chain in this direction which more than compensates for the increased latitude.

In the Coast Ranges of British Columbia, on the other hand, as might be expected from their position with reference to the direction of the prevailing

* Professor Davidson, in giving the elevation of Mount Baker as determined by the Coast Survey, adds that the height of the snow-line on the west side of the mountain was found to be 5,301 feet, which he says "is 2,150 feet higher than the elevation reported by Alexander Agassiz, which has generally been distrusted." From what has been previously stated in this chapter in regard to the varying amount of snow on Mount Shasta, it will readily be inferred that any such thing as a fixed snow-line on these volcanic cones does not exist in nature.

winds and their proximity to the ocean, glaciers exist in abundance above the 49th parallel, and increase in size as we follow the chain towards the northwest. Below the 51st parallel they only occur high up in the range; but, north of that, begin more and more to extend down the valleys, and finally, in still higher latitudes (about 60°), come nearly or quite to the sea.

Returning to our own territory, the conditions as to the present distribution of snow on the Great Basin ranges, and in the higher portions of the Rocky Mountains, between the parallels of 37° and 43°, may be noticed. In all this region, as before remarked, there are, so far as known, no active glaciers, with the exception of the very small ones recently discovered near the summits of one or two of the highest points of the Wind River Range. The condition of this region, as respects snow accumulations, resembles much that already described as prevailing in the Sierra Nevada, but, on the whole, with less fluctuation from year to year.

The mountains nearest the Sierra on the east, the Inyo and White Mountain ranges, have their precipitation cut off almost entirely by the more elevated range on the west. The contrast between the amount of rain and snow fall on the Inyo Range and the Sierra Nevada is most striking. The former runs parallel with the latter, is not very much inferior to it in elevation, and the crests of the two ranges are hardly more than twenty miles apart, a valley some 10,000 feet deep intervening. Yet hardly any snow or rain falls on the Inyo Range, which is quite destitute of any streams on either flank, and indeed furnishes hardly water enough to keep the explorer from perishing with thirst. At a time of the year (May, 1872) when the Sierra was deeply covered with snow for from 2,000 to 3,000 feet below the summit of the range, the Inyo Mountains opposite hardly showed the smallest trace of it.

Snow remains in patches on the highest points of the most elevated ranges of the Great Basin, especially the East Humboldt, through the whole year; but the amount still left at the close of the drier seasons must sometimes be exceedingly small. There are no statistics of the precipitation on these ranges, but there can be no question that it is small, as compared with that on the Sierra Nevada. As we approach the eastern edge of the Cordilleras, the regimen of the climate changes somewhat, the rain and snow fall being no longer limited essentially to the winter season, but extending over the whole year. Still, in spite of its more equal distribution, the quantity does not appear to be as large as it is on the Sierra. The writer, with a small party, spent the summer of 1869 on the highest portion of the Rocky Mountains, near South Park, and on the western side of the head-waters of the Arkansas River. During the months of July and August of that year there were never as many as three consecutive days without rain, and only rarely as many as two. The rain-fall was quite tropical in character, beginning about noon, and usually lasting until evening, with occasional violent showers. In some instances snow fell on the summits of the highest peaks; but as a general rule the precipitation did not seem to extend up as high as that. Thunder and lightning, sometimes very severe, almost invariably accompanied these rain-falls. In spite of the great number of rainy days, however, the ground was never more than superficially wet, evaporation taking place with the greatest rapidity, and the whole aspect of the Arkansas Valley was that of a dry country.

Nowhere on the higher portions of the ranges adjacent to South Park was anything seen approaching a glacier in character. There were patches of snow, sometimes of many acres in extent, in sheltered nooks, and in depressions on the northern slopes of the higher peaks. The amount of snow remaining through the season did not appear to differ much from the average quantity left on portions of the Sierra Nevada of corresponding elevation, and in the same latitude.

Having thus given a general view of the present condition of the Cordilleras with regard to the occurrence of snow and ice, we shall now be prepared to discuss the phenomena of former glaciation in the same region. From what has been said in the preceding pages, it will be evident that, at the present time, there are no glaciers within the limits of the United States possessing any considerable significance as geological agents. It is only at some distance north of our territory and along the Pacific Coast that what may be properly called a system of glaciers occurs, and which, although up to this time only very imperfectly explored, is undoubtedly attended by the usual interesting accompaniments of the formation of moraines and other glacial phenomena on a large scale. But, as already suggested, there has been in former times a very extensive development of glaciers, not only in the Sierra Nevada, but in the Rocky Mountains also, while indications of their former presence are not entirely wanting in the ranges of the Great Basin itself. For convenience of description we may begin with the most southern portion of the Sierra Nevada at which traces of former glaciation have been observed, and, following the range northward, give such particulars as have been obtained in this connection during the various explorations and reconnaissances of the Geological Survey in that region.

At the time of the beginning of the California Survey nothing was known in regard to glacial phenomena in the Far West. It was generally assumed that the ice-capping of the northern hemisphere was something which extended all around the pole, and it was presumed that what was true for New England in respect to ice-action would be found to hold also in similar latitudes in the western regions on to the Pacific.

It was with no small interest, therefore, that we began to study, in 1860, the distribution of the surface detritus on the Pacific coast with reference to the question of ice-action. Our first year's work was entirely or chiefly in the Coast Ranges, and it was clearly established by our examinations, which during that year extended from near the southern border of California to a hundred miles north of the Bay of San Francisco, that here was no question of either glacial or northern drift. All the loose materials on the surface showed themselves to have been distributed by causes similar to those now in action. Detrital materials were always found to have been carried by water down the slopes of the mountain ranges. The source of the débris at the mouth of any cañon was always to be found up the cañon, and not at any point to the north or in any other general direction. There was no striation, or other marking of the rock surfaces, such as could only be attributed to the sliding over them of icy masses. The next year, however, took us into the Sierra Nevada, and here we did not fail to discover abundant proof of the former existence of glaciers on a large scale. The exploration of 1862, 1863, and 1864 showed us that large glaciers had once covered a considerable portion of the Sierra, but only the higher portion; that in certain favorable positions, where there was a large gathering-ground for the ice, — a cirque of vast dimensions, as at the head of the Tuolumne River, — these glaciers had formerly descended to a level of between 3,000 and 4,000 feet above the sea. In the Southern High Sierra, between the parallels of 36° and 37° 30′, the same condition of things was observed in 1864; abundant proof was obtained of the former existence of glaciers, which had, under favorable circumstances, descended to a pretty low level, and had left, as proof of their former presence, magnificent moraines, — medial, lateral, and terminal. The rapid rise of the Sierra as we proceed southwards from the head of the Tuolumne, fully compensates for the decreased latitude, so that the glaciers were as fully developed between the parallels of 36° 30′ and

37° 30′, that is about the head of the San Joaquin and King's rivers, as in the upper valleys of the Tuolumne. South of 36° the chain falls off at once, and beyond that point to the south no trace of former glacial action has been discovered by any member of the California Survey.

Going north, on the other hand, from the Tuolumne, the Sierra Nevada diminishes rapidly in elevation, the passes sinking from 10,000 to 7,000 feet, and the crest height being but little greater than the pass height. This decreased elevation more than counterbalances the gain in latitude, so that there are no more such proofs of long glaciers as that of the Tuolumne, which was between forty and fifty miles in length, to be seen. The glaciers about the head of the forks of the American River were large, it is true, but not to be compared with those on the Tuolumne and the San Joaquin. North of the head of the American, it would appear, from all our observations, that the ancient glaciers were but small, and we saw but faint traces of their former existence around Lassen's Peak, or in the region beyond that cone of nearly 11,000 feet in height, along the volcanic plateau towards the foot of Mount Shasta.

The region around Mount Shasta was only very hastily examined by the Geological Survey, and no striking indications of former glaciation were observed around that great cone by any member of the corps at that time. Later, Mr. King, as already mentioned, made a detailed exploration of the mountain, and discovered abundant evidence of a previously greater extension of the glaciers now existing on its northern slope.

The country north of Mount Shasta was examined at different times, both by the writer and Mr. Gabb, as far north as Vancouver Island and New Westminster on the Fraser River. What was observed in the course of those explorations will be mentioned further on in this chapter.

Returning now to the Sierra Nevada, for the purpose of giving the necessary details in regard to the occurrence of the ancient glaciers of that range, it will be desirable to fix as nearly as possible the most southerly point at which unmistakable signs of former glaciation have been observed.

Nothing has been seen, so far as known, of any glacial markings in the high peaks and ranges of the southern part of the State of California. Neither in the San Jacinto, San Bernardino, or San Gabriel ranges have any such indications been observed. These ranges are from 8,000 to 11,000 feet in altitude, and cover an extensive area; but the latitude is too southerly. It is true that there are curiously deceptive appearances which are of frequent occurrence, and which may be mistaken for glacial phenomena by inexperienced observers. The peculiar weathering of the granite outcrops in the Sierra has been repeatedly mentioned in the Geology of California, and need here only be recalled to mind as the cause of many misconceptions. Some ridges, as, for instance, one on the north side of the Temescal Range,* are covered with rounded masses of rock, which at a little distance, and without close examination, seem to be unquestionably drift boulders. They are, in point of fact, the remains of the disaggregation by weathering of the concentrically laminated granite, as is easily recognized, when it is observed that the rock may be found in all stages of passage from the almost solid ledge, faintly marked with concentric bands of color and fine lines or cracks, up to the entirely detached and boulder-like masses which rest on the surface, as if brought from a distance and deposited there by ice or water. Sometimes, however, the granite, instead of assuming regularly rounded forms, takes on the most fantastic shapes. A locality of this kind may be seen near Lone Pine, in the valley of Owen's Lake, along the west side of the so-called Virginia Hills.

Another source of error, especially apt to be met with in the ranges of mountains of the southern part of California, is found in the way in which detrital materials have often been carried down the cañons, entirely beyond the edge of the mountains, and spread out on the adjacent plains. This kind of occurrence has already been described in the gravel volume in speaking of the great "washes" at the base of the high ranges. It need only here be noticed that such washes always spread out fan-shaped from the mouth of the cañon from which they issue, while true moraines as invariably lie in parallel lines. The former also always present in a cross section parallel with the range a nearly uniformly rounded surface, the highest portion of which is directly opposite the mouth of the ravine; moraines, on the contrary, exhibit evidence of having been piled up on each side of an advancing mass of ice, in that they form two very distinct lines of accumulated material, with a deep depression between them and opposite the centre of the cañon.

As already mentioned, the Sierra falls off very rapidly in elevation, from a point about opposite the lower end of Owen's Lake. The range here consists of three principal parallel branches, having the continuation of Owen's Valley, south of the lake of that name, on the east, and Tulare Valley on the

* See Geology of California, Vol. I. p. 179.

west. The two interior valleys formed by the three ranges are very deep cañons with precipitous sides, and are drained by the branches of Kern River, of which the more westerly one, not far from seventy miles in length, heads to the north of Owen's Lake, on the south flanks of the Mount Brewer Group. The regular line of travel for wheeled vehicles across the Sierra, connecting the Tulare Valley with Owen's Valley, crosses the range about fifty miles south of the southern end of Owen's Lake. This pass is a little over 5,300 feet in elevation, and the adjacent mountains are about a thousand feet higher than this. There is no wagon-road across the Sierra between the Walker's Pass and the Sonora Pass roads, a distance of somewhat over 200 miles measured in a direct line along the crest of the range. There are three foot-trails between the two wagon-roads mentioned, one leading up the Tuolumne Valley to Lake Mono, and two others crossing near Owen's Lake. The most northerly of these two leads from Visalia in a northeasterly direction, crossing the Sierra by Mount Brewer and Kearsarge Mountain, and descending into Owen's Valley opposite the town of Independence; the other crosses the summit of the eastern ridge of the Sierra at a point nearly opposite the centre of Owen's Lake, descending to Lone Pine. The two trails are about thirty miles apart; the northern one, the highest point of which is not far from 12,000 feet above the sea-level, is called the Kearsarge; the other, which is known as the Hockett (or Hackett) trail, is about 11,000 feet in elevation.

The descent of the Main or western branch of the Kern is exceedingly rapid, it being not less than 10,000 feet between its head and Kernville, the point at which the Walker's Pass road meets that river, here 2,490 feet above the sea-level. Of course it would not be expected that the glacier which once occupied the head of the Kern would have descended as low as this; and, in point of fact, no traces whatever of any former glaciation were observed, either by the writer or by any of his corps, at any point on the Walker's Pass route. All of that portion of the Sierra which lies between the last-named road and the Hockett trail was mapped by Mr. R. D'Heureuse, of the State Geological Survey. His notes make no mention of any glacial markings in this region, although it is not probable that his attention was particularly called to this matter. Mr. Goodyear, however, in 1872, made a special visit to the Mount Whitney region, crossing the mountains on the Hockett trail. In his report of this journey,* he says: "Another point of

* See Proceedings of the California Academy of Sciences, Vol. V. p. 182.

some interest is, that though I hunted for them, I found no glacial scratches, nor any other evidence of the former existence of glaciers anywhere in this portion of the mountains; not even on the peak which has been mistaken for Mount Whitney, and which is over 14,000 feet high; nor on the top and sides of another peak which I climbed in the *western* summit, four or five miles northwest of Soda Springs, and which cannot be much less than 12,000 feet high; nor in the cañon of Kern River which I followed, for four or five miles, — nor anywhere I went did I find any traces of glaciers. This is certainly somewhat remarkable, when we consider the fact that the mountains only twenty miles to the north are, according to all accounts, full of glacial markings. It is true that much of the granite in the region where I travelled is comparatively soft; but this is by no means the case with all of it, and much of it is as hard, and as well adapted to preserve such markings, as any in the Sierra."

It appears, therefore, while the very upper portion of the main branch of Kern River was undoubtedly occupied in former times by ice, the glacier extended only a short distance to the south; and that, although originating in the very highest part of the range, it was far inferior in importance to some of the masses of ice occupying depressions in the range farther north. The reason of this small development of the Kern River glacier is undoubtedly chiefly to be found in the fact, that the most westerly of the three parallel ridges into which the Sierra is here divided almost entirely cuts off the precipitation from the other two. On the west side of the main Kern is the range of the Kaweah Peaks, which is but little inferior in altitude to the main water-shed, or the portion of the range which divides the waters flowing into Owen's Valley from those finding their way to the Kern River. These two nearly parallel elevated ridges are about fifteen miles apart. We have here, therefore, another excellent illustration of what has already been stated to exist, in reference to the relations of the crest of the Sierra Nevada in this region to the Inyo Mountain Range on the east; from which latter the precipitation is almost entirely cut off by the superior elevation of the closely adjacent line of summits on the west. Still another reason exists why no long glacier found its way down the main branch of the Kern. The topographical features of the Sierra in the region lying between Owen's Lake and the Kaweah River are not favorable to the development of a large glacial system. The Kern runs in a narrow and extremely precipitous valley, which does not open out at its head, so as to form a large gathering-ground for the snow and ice. The direction, during all the upper part of its course, is parallel with the trend of the Sierra, and an inspection of the map will show at once how limited its area of drainage in the higher part of the range is, as compared with the other principal rivers farther north.

Three rivers of the Sierra Nevada presented in their upper basins all the conditions necessary for the formation of large *mers de glace*, and they were thus occupied at no very distant period: these were the King's, the San Joaquin, and the Tuolumne. Of these grand glacial masses probably that of King's River was the largest, because the area of drainage of this river is greater than that of either of the other rivers named, while the average height of the chain in this portion of its extension is greatest. The most elevated region drained by the King's is that included between Mount Brewer, Mount Tyndall, and Kearsarge Mountain, there being here a triangular area, the lowest part of which has an altitude of over 10,000 feet above the sea-level. The North Fork of the King's does not head in the main range of the Sierra, but to the west of the Mount Goddard Group, being lapped around by the South Fork of the San Joaquin. The length, in a direction parallel to the axis of the Sierra, of the area drained by branches of King's River, is about fifty miles; but they only head up as high as the main divide for a distance of about thirty miles. The North Fork joins the main stream about six miles below the junction of the Middle and South Forks, and this is about thirty miles in a straight line from the crest of the Sierra. The valley in the neighborhood of the junction of the three branches is from 6,000 to 7,000 feet in altitude, and was formerly occupied by the united ice-streams coming in from above. Allowing that one third of the surface of the basin above this point was covered by the King's River system of glaciers, the connected ice-mass must have had an area of somewhat over 300 square miles. All through this region, the lower portions of the valleys are smoothed, scratched, and polished, and lateral and medial moraines occur on the grandest scale; but nowhere were any markings observed at a lower altitude than 4,000 feet above the sea-level. Professor Brewer, in his notes of his examination of this region in 1864, says: "The entire absence of observed glacial traces at lower levels makes it almost certain to me that the glaciers did not descend to below 3,000 feet, and indeed no traces have been seen below 4,000 feet."

The moraines in the upper portion of the King's River basin are among the largest and most perfect which have been observed anywhere in the

Sierra. The main glacier came down from the vicinity of Kearsarge Mountain along the route of the present trail. About six miles from the summit, here over 12,000 feet high, it was joined by a side-glacier coming in from Mount Brewer on the south. Between these two ice-masses a moraine was formed, of which the present appearance is that of a vast embankment of loose boulders and angular fragments of rock, piled up with the steepest slope on which such materials will lie without sliding, the upper edge of the western side being elevated from 1,400 to 1,500 feet above the bottom of the valley. On the eastern side, or that nearest to Mount Brewer, is a depression having a depth of from 400 to 500 feet. On the opposite or western side of the valley is the corresponding lateral moraine, at a distance of about a mile and a half, having nearly the same altitude as the other one, but being considerably smaller. The tops of these moraines, especially of the eastern one, are quite smooth, and are covered with boulders, and they have a gentle inclination up the valley, looking in the distance as regular as railroad embankments.* To ascend or descend the sides of these moraines with animals was a very difficult task; to travel along on their crest, comparatively easy. The former thickness of the glacier at this point, as estimated by Professor Brewer, must have been at least 1,300 or 1,400 feet; a mile farther up the valley he estimated it at not less than 1,800 feet. The valley between the two moraines is pretty free from detritus, and beautifully scored and polished.

On the eastern slope of the main range of the Sierra, opposite the head of Kern and King's rivers, glaciers undoubtedly once existed; but they did not descend into Owen's Valley, or even approach it within considerable distance. The flanks of the range between Owen's Lake and the Fish Springs volcanic group are covered up to a perpendicular height of over 2,000 feet with the "wash" previously described, and commonly called the sage-brush slope. There are no data in the writer's possession from which it can be clearly made out how much the glaciers, at the time of their greatest extension, lacked of reaching this belt of detritus. Explorations made in 1872 along the flanks of the range rendered it evident that the ice could not here have descended as low as a line 7,000 feet above the sea-level; but there was too much snow on the mountains at that time, the month being May, to obtain any satisfactory evidence on this point.

The valleys occupied by the various branches of the Upper San Joaquin

* See Geology of California, Vol. I. p. 379, for a section across these moraines.

present also the usual phenomena of former glacial action on a magnificent scale. The main tributary of this river in the High Sierra is the so-called South Fork, which heads in two streams, one coming down from the north side of Mount Goddard, and the other from the north end of the Palisades. The principal stream, receiving many tributaries, runs about fifty miles in a direction parallel with the axis of the chain, or northwest, and then unites with the North Fork, a much smaller branch coming down from the portion of the ridge between Red Slate Peak and Mount Lyell. The total length of the portion of the Sierra drained on its western slope by the San Joaquin is between fifty-five and sixty miles. This area has been but very imperfectly explored by the Geological Survey; but abundant evidences were obtained of the former existence of glacial masses in this region, on a scale perhaps even grander than in the King's River area. In the valley of the San Joaquin, on the South Fork, Professor Brewer inferred, from the position of the old moraines, that the former glacier must have been at least 1,500 feet deep, and eight or nine miles wide in its widest places. The length of the whole South Fork glacier, measuring to the termination of the ice in the Main Valley, must have been over fifty miles. Neither in the case of the King's nor the San Joaquin River glacier has the precise point of the valley reached by the glacial mass at the time of its greatest extension ever been ascertained.

The formerly glaciated portion of the Sierra Nevada, which has been most carefully explored by the Geological Survey, is that at the head of the Tuolumne River. This region, from its importance as being in the most accessible part of the range, near the Yosemite Valley, and consequently much more visited by pleasure-travellers than the Southern High Sierra, was mapped on a larger scale than the rest of the range,* and sufficiently studied to make it possible to lay down the position and extent of the ancient glacial mass with considerable approach to accuracy.

The length of that part of the Sierra which is drained by the Tuolumne, measured parallel with the axis, is a little less than forty miles. The principal gathering-ground of the glacier was in the elevated plateau-like region embraced between Cathedral Peak, Mount Conness, Mount Dana, and Mount Lyell, forming an irregularly shaped area of some sixteen miles in length and from six to ten in breadth. The lowest part of this area is a little less

* This map, comprising about 2,500 square miles, and on a scale of two miles to an inch, accompanies the 4to and 8vo editions of the Yosemite Guide-Book. A reduced photolithographic copy, on a scale of three miles to an inch, is also given in the 16mo edition of the same work.

than 9,000 feet in elevation, and the ice in this portion of the valley must have formerly been over a thousand feet in thickness. Into this basin came down branches of the ice-flow from the Mount Conness Range on the north, from the pass just north of Mount Dana, formerly known as McLane's Pass, and from Mono Pass on the east, and from the mass of Mounts Maclure and Lyell on the south, this latter being the most extensive of all. The lateral and medial moraines of all these different flows are as plainly visible on the surface as if the ice had but just melted away and left them. They are particularly well marked where the glacier coming down from Mono Pass united with that descending from McLane's Pass.

At Soda Springs the valley of the Tuolumne begins to narrow gradually, and two miles below commences the remarkable gorge which continues for twenty miles as a grand cañon, with extremely precipitous walls from a thousand to fifteen hundred feet high, between which there is hardly anywhere much more than room enough for the river to run over its rocky bottom. The walls of this cañon, however, although very steep, are nowhere perpendicular as in the Yosemite; neither are there any of those sudden perpendicular drops of its floor, such as we have where the Merced falls over the squarely-cut granite edges in plunges of 600 and 400 feet at the Nevada and Vernal Falls. The whole of this cañon of the Tuolumne has been occupied by a glacier, as both the bottom and the sides show abundant evidences of glacial striation and polish. Detrital accumulations, however, are extremely rare in it. The facts observed prove very clearly that the form of the cañon has been in no respect due to ice-action. Projecting edges have been rounded and smoothed. But the ice-mass followed the channel previously prepared for it: it did not do the work of excavation itself. A brief study of the position of the glacial markings is sufficient to establish the fact that the cañon could never have been excavated by the glacial mass which once filled it.

If it be asked *how* this is shown, the answer can be very easily given. If the cañon had been excavated by the movement of the ice with which it is admitted that it was once entirely filled, it would of necessity show that this was the case by presenting exclusively, everywhere in its course, the characteristic features due to ice-work. To use a homely illustration: if one were to work out a trough in a plank with sand-paper alone, the resulting cavity could not have angular recesses and projecting edges in it, for sand-paper is a tool or material which cannot originate forms of that kind. So, in the Tuolumne Cañon, the larger portion of the surface is rough and angular, showing deep recesses, and squarely-cut buttresses, which sometimes project out directly in the path of the ice, as if on purpose to brave its erosive power. Only in places is even the bottom entirely smoothed over; while the walls have only those projecting edges and surfaces rounded and polished which faced the direction from which the ice was moving, or projected out into the valley so as to be easily reached by it. Hence it seems reasonable to infer that ice has done but a very small part of the work of excavation, which was in reality performed by other vastly more potent agencies.

The Tuolumne River in the cañon has a rapid fall, averaging about 200 feet to the mile, the stream itself varying greatly in size with the varying conditions of the years and the seasons. A considerable part of its descent is made by a series of beautiful cascades over shelving rocks, the scenery being extremely grand and attractive, although by no means to be compared with that of the Yosemite Valley.*

North of the Tuolumne Cañon, and west of the Mount Conness Range, is an elevated plateau-like area of almost bare granite, which rises gradually towards the northeast, and culminates in the range dividing the head-waters of the Tuolumne from those of Walker's River, and of which the grand and jagged mass of Tower Peak is the dominating point. This plateau is intersected by several parallel streams which run in a southwest direction from the Tower Peak Range, and enter the Tuolumne Cañon over its edge in a series of falls and cascades, which are described, by those who have seen them at a time when greatly swollen by the melting of the winter's snow, as being very grand. All this granite slope is beautifully polished and striated, and the mass of ice which once covered it must have chiefly found its way into the Tuolumne Cañon, and added to the volume of that great mass of ice. It needs but a glance at the map to see how exceptionally favorable the conditions were in this part of the Sierra for the formation of a large glacier; and it is thus easy to account for the great length of this one, as compared with those farther to the north in the range, where there is no recurrence of similar topographical features on anything like the scale exhibited at the head of the Tuolumne.

Below the gorge just noticed, the cañon opens out and presents a remarkable counterpart of the Yosemite, known by the name of the Hetch-Hetchy

* For some details in regard to the scenery of the Tuolumne Cañon, the Yosemite Guide-Book, edition of 1874, may be consulted.

Valley. This has been sufficiently described in the Yosemite Guide-Book; but a few words must here be added in regard to the interesting glacial features of this curious locality. The Hetch-Hetchy is about fifteen miles northwest of the Yosemite, and is similarly situated with reference to the crest of the Sierra, from which its upper end is about twenty miles distant. Both these valleys have been lakes in former times, and the Hetch-Hetchy still becomes one not unfrequently, the gorge below it being too narrow to carry off all the water at the time of the melting of the snow in the spring. The bottom of the valley is about 3,650 feet above the sea, or about 300 feet lower than the Yosemite. Unlike the latter, it is separated into two pretty distinct divisions by a precipitous spur of granite, which projects out from the southern side, and the sides of this mass, as well as the walls of the valley, are beautifully scored and polished up to a height of at least 800 feet above the level of the river. The walls of the Hetch-Hetchy are nearly 2,000 feet in height, and very precipitous, with but a small amount of talus at the bottom, as is the case in the Yosemite. No doubt the exact thickness of the glacier by which it was formerly filled could be accurately determined by careful examination. From the observations of Mr. Hoffmann, by whom this interesting locality was first made known to the public, it appears that below the Hetch-Hetchy the trail runs for some distance along the top of a moraine, at an elevation of 1,200 feet above the level of the river. The valley has not been explored below the Hetch-Hetchy for the purpose of ascertaining the exact point to which the Tuolumne glacier descended at the time of the greatest extension of the ice; but it must have reached nearly or quite down to the junction of the South Fork. In that case the total length of the mass of ice would have been about fifty miles; it was certainly over forty. The width must have been more than four miles at some points in its course, and it may in places have exceeded six.

Between the San Joaquin and the Tuolumne rivers is the Merced, the glaciation of whose valley is next to be discussed. This stream is more interesting than any other in the High Sierra, because it is the only one much seen in the upper part of its course by travellers and tourists, since it runs through the Yosemite Valley, the one feature of Californian scenery which attracts universal attention. It is the more desirable that the glaciation of the Merced Valley, including the Yosemite, should be somewhat minutely described, because there seems to be a strong feeling, in California at least, that the remarkable scenic features of that locality are, in some way, the result of glacial action. It seems surprising that a theory so utterly averse to the facts should have ever gained currency, and it is almost humiliating to be obliged to enter into an argument to prove that the Yosemite Valley was not dug out of the solid granite by ice.

The head of the Merced hardly reaches the summit of the Sierra. It is lapped around by branches of the San Joaquin on the south, and of the Tuolumne on the north. All three of these streams head in the great central mass of which Mount Maclure and Mount Lyell are the dominating peaks. From this nodal point, however, great spurs extend to the southwest and northwest, enclosing triangular areas between themselves and the main divide, and which are drained by the tributaries of the San Joaquin and Tuolumne, thus limiting the extent of the real summit range included in the basin of the Merced to a distance of hardly more than a couple of miles on the west side of the Mount Lyell Group.

The real sources of the Merced are the various streams coming down from the southwest side of the spur of the Sierra which leads from Mount Maclure to Cathedral Peak, and from the northeast flanks of the Mount Clark Range. The latter is a lofty mass of granitic rocks, which runs parallel with the main crest of the Sierra, at about eight miles' distance, and is connected with it by a transverse ridge. The plateau-like space thus enclosed is about eight miles by ten in dimensions, with sides rapidly descending towards the centre, where in a deep cañon runs the Merced. The lower portion of this quadrangular area was formerly occupied by a glacier whose arms extended up the depressions between the different spurs coming down from the main ridges enclosing it on three sides.

The glacier which was thus formed at the head of the Merced was probably not by any means as thick, and it certainly was not so extensive, as that which occupied the Upper Tuolumne Valley on the other side of the Cathedral Peak Range. The reasons of these inferior dimensions are easily found in the smaller size and diminished altitude of the gathering-ground at the head of the Merced. This latter is nearly two thousand feet lower, on the average, than the broad valley to the north, which formed the main reservoir into which descended the numerous tributaries which combined to form the main glacier of the Tuolumne. The area at the head of the Merced, besides having the disadvantage of inferior altitude, is so situated that it could receive only one important tributary, namely, that coming down on the east side of Cloud's Rest, and which was, in fact, simply an overflow from the vastly greater mass of the Tuolumne glacier.

The Little Yosemite is a flat valley or mountain meadow, about four miles long, and from half a mile to a mile wide. It is, essentially, a continuation of the Great Yosemite on a somewhat diminished scale, and is separated from it by only a couple of miles of distance, in the course of which the Merced River descends 2,000 feet, half of which is in two perpendicular falls, the Nevada and the Merced. The walls of the Little Yosemite are irregular in form, and consist of almost bare granitic masses, showing everywhere a most perfectly developed concentric structure. Down this valley the Merced glacier passed, and just above the Nevada Fall it was joined by the branch from the Tuolumne glacier, as already mentioned. The moraines left by this last-named branch, along the back or eastern side of Cloud's Rest, are very conspicuous objects to the traveller following the trail from the Yosemite over to Soda Springs in the Tuolumne Valley, and they are indeed much larger than any of the moraines noticed as belonging to the Merced glacier proper. Just to the southeast of Cloud's Rest the moraine summit was found to be 765 feet above the Merced River; but it does not come within 1,500 feet perpendicular of the crest of the ridge of which the Half Dome and Cloud's Rest are the two culminating points. The last traces which could be found of the Merced glacier were at a point a little above the Nevada Fall. The most careful search failed to reveal any signs of glaciation in the cañon below the fall. Nor were there any scratches or polished surfaces found on the high points immediately south of the Little Yosemite, especially in the vicinity of Mount Starr King, a curious, isolated, inaccessible cone of granite, rising among a group of similar elevations.

Another arm, or overflow, of the Tuolumne glacier came down the cañon of the Tenaya Fork of the Merced, on the west side of Cloud's Rest; and it was in all probability joined by an independent ice-flow of considerable dimensions coming in from the east side of the Mount Hoffmann Range. The highest point of this group of summits, which lies about midway between the Yosemite and the grandest part of the Tuolumne Cañon, is nearly 11,000 feet in elevation; the pass leading from Tenaya Lake, at the head of the Tenaya Valley, over to the Tuolumne Valley, is about 9,000 feet above the sea-level. All through this region the rocks are beautifully polished and striated, and these evidences of former glacial action are especially conspicuous about Tenaya Lake, at the head of which is an isolated conical knob, which rises to a height of about 800 feet above the level of the lake; its sides, nearly or quite to the summit, offer abundant traces of glaciation. The contrast between the sharp pinnacles of which the highest points of the Cathedral Peak Range are made up and the rounded and polished surfaces in the valley below is most striking.

The descent of the Tenaya Fork to the Yosemite is very rapid; the distance from the lake to the valley being about ten miles, and the difference of elevation fully 4,000 feet. Thick as were the ice-masses at the head of the Tenaya Cañon, the most careful search failed to reveal any proof that they had ever descended so far as to reach the Yosemite itself. The lower part of the cañon is pretty much choked up by huge blocks of granite which have tumbled from the adjacent precipitous walls; but neither the rock in place nor the loose masses exhibited any signs of striation.

It would appear, therefore, that neither the Merced glacier nor the overflow of the Tuolumne ever descended so far as the Yosemite; consequently the ice never entered this valley, as it could only have been supplied to it from those sources.* The walls of the Yosemite on each side were carefully examined by the writer without his having been able to find on them any signs of smoothed, striated, or polished surfaces which could be unhesitatingly set down as the work of ice. There are, it is true, many places where the surface of the granite is very even and smooth; but a close inspection will always be sufficient to establish the fact that this is a structural peculiarity of the rock itself, and not of glacial origin. All throughout the Sierra, as has been already mentioned, but especially in the vicinity of the Yosemite, the granitic masses have a most marked tendency to separate in concentric shells. This structure, which seems to pervade the rock to a great depth, impresses itself most strongly on the scenery, the surface seeming to be covered with a succession of domes and conical knobs, some of which, as in the case of Mount Starr King, rise up so steeply as to be quite inaccessible. As these shells or plates separate from each other under the influence of varied me-

* The statements made by the writer in the Geology of California, Vol. I., to the effect that a glacier had once filled the Yosemite Valley, is an error, which has long since been corrected in the various editions of the Yosemite Guide-Book. The mistake was caused by too much dependence being placed on the reports of assistants entirely inexperienced in the study of glacial phenomena. Since the Geology of California, Vol. I., was published, the Yosemite and the adjacent region have more than once been carefully examined by the writer himself.

Mr. J. F. Campbell, author of "Frost and Fire," a practised observer, says, in his work entitled My Circular Notes, "A local geologist found marks which indicate the presence of a large glacier in the Yosemite Valley; *I sought carefully, and found no marks of glaciation there.*"

teorological conditions, they expose great rounded surfaces, of which the smoothness is well calculated to deceive careless or inexperienced observers. Similar surfaces may, however, almost invariably be found in the immediate vicinity of such exposures, where the conditions are such that it is seen at once that ice cannot have been the agent in bringing about the peculiar smoothness and curved form of the rock. There are plenty of deeply recessed portions of the Yosemite Valley, where at the bottom of a cavity entirely inaccessible to ice the same smoothness may be observed. Around these are the overlapping edges of the successive plates, by the removal of parts of which the cavity has been formed. These will all have sharp edges, an occurrence entirely impossible if the removal of the wanting portion had been effected by glacial erosion.

The only thing in the Valley which might with some plausibility be referred to the agency of ice is the small moraine-like elevation at the head of the Bridal Veil Meadow, referred to in the Geology of California, Vol. I. This, as well as the whole Valley, the writer has re-examined since that volume was written, and has become thoroughly convinced that it is not necessarily of glacial origin. A moraine in the Yosemite Valley would without doubt be composed of similar materials to those which constitute the present talus at the bottom of the walls of the Valley. These are all made up chiefly of coarse angular blocks of granite with a little finer granitic detritus mixed with them, such material, in short, as would be formed by the cracking off and falling down of portions of the walls of the Valley. The supposed moraine, however, is made up of fine material almost entirely, and it appears very probable that it was formed at the time when the Valley was a lake, by the crowding of the ice against the shore, at the time of the winter's freezing. This mode of building up of walls and moraine-like accumulations around the shores of lakes is a phenomenon of frequent occurrence. In the case of the Yosemite the formation of such a pile of débris at its lower end would be materially aided by the violence with which the wind frequently blows up or down the Valley. This, even now, is occasionally almost submerged at the time of the most rapid melting of the snows on the adjacent heights, after winters of uncommonly large precipitation. The Hetch-Hetchy, on the other hand, according to Mr. Hoffmann, is transformed into a regular lake at such times.

It being, as the writer after a careful examination believes, a well-established fact that the Yosemite was not occupied by ice during the time of the former extension of the glaciers over the higher portions of the Sierra, a few words may be added to what has been said, for the purpose of showing that, even had the Valley been so occupied, there is no reason to believe that its form would have been essentially modified by any erosive agency of the ice which passed through it. Bearing in mind what has already been said in regard to the glaciation of the Tuolumne Cañon and the Hetch-Hetchy Valley, it may be added that the form of the Yosemite is still more unlike anything that could have been effected by any kind of erosive action, whether of ice or water. Following down the Merced from the Little Yosemite, we have in the first place two vertical steps of descent, of 600 and 400 feet. Even now, after the river has poured its volume of water over these precipices for ages, their edges remain wonderfully sharp. These vertical steps downwards along the line of descent of the supposed glacial mass are something of an entirely different nature from any results which either ice or water is accomplishing at the present day. But the whole Yosemite shows in all its details a succession of forms which never could have been produced by any kind of erosion. Such rectangular, squarely cut recesses as that at the head of the Valley, over which the Vernal and Illilouette falls descend, could never have been produced by flowing material of any kind. And all through the Yosemite there are vertical, or nearly vertical, walls of rock from one to two thousand feet in height, which are turned entirely in the opposite direction, and, so to speak, hidden away from any possible approach of an erosive agent. An examination of the large map of the Valley accompanying the 8vo and 4to editions of the Guide-Book would suffice to convince any candid inquirer that such faces of rock as those on the west side of El Capitan differ radically from anything exhibited by ordinary valleys of erosion. A moving mass of ice could only have acted in the direction of its own line of motion. Angular forms could never by any possibility be cut out at right angles to that direction. Most surprising, and contrary to all the facts, is the attempt which has been made to explain such remarkably exceptional formations as that of the Half Dome by glacial erosion. The summit of this stupendous mass rises to a height of more than 2,000 feet above any point which ice could ever have reached. It has not a glacial scratch upon its surface at any point. Its smoothly rounded back and dome-shaped summit are found on examination to be strictly conditioned by the internal structure of the mass itself, which along the edges of its broken front everywhere shows the overlapping concentric shells of which it is made up. As if to remove every possibility of a glacial theory of its origin, it presents in precisely the direction from which any moving body of ice must have approached, — namely, towards the head of the Tenaya Cañon, — a series of immense projecting plates, the edges of which are sharply cut and do not exhibit the least indication of rounding by glacial or any other erosive force.

Below the Bridal Veil Meadow, at the lower end of the Yosemite proper, the whole character of the valley changes; the sides assume the ordinary V-shape due to erosion by water, and the piles of débris at their base become conspicuous. All the characteristic Yosemite features, — the vertical walls, the rectangular projecting cliffs, the almost entire absence of talus, — these all disappear as soon as we enter the cañon below.

All along the Sierra Nevada in the vicinity of the head of the Tuolumne River, there is abundant evidence that the glacial masses covering so extensive a portion of the western flanks of the range also extended far down on the eastern side. Above the group of volcanoes near Fish Springs in Owen's Valley, the eastern slope of the Sierra has been but very slightly examined by the Geological Survey. The deep cañons down which Big Pine, Bishop's, and Indian creeks descend are, in all probability, glaciated in their upper portions; but there seem to be no morainic accumulations of great size reaching to a considerable distance below the summit, as is the case farther north. All along this side, however, from Round Valley north, as far as Big Meadows, twenty miles beyond Mono Lake, the moraines left by the glaciers formerly descending the eastern slope are extremely conspicuous.* A very extensive glacier formed on the east side of the high group of summits to which Mount Ritter and Mount Maclure belong. This body of ice pushed its moraines at least six miles to the north, towards Mono Lake. At the southern end of this lake is an extensive group of volcanic cones and craters, which rise to the height of from 9,200 to 9,300 feet above the sea, the highest being about 2,750 feet above the level of Mono Lake. These cones, which are chiefly made up of ashes and pumice, have retained their original shape in almost entire perfection, showing that the amount of precipitation in the form of rain in this region must be very small, as otherwise they could not fail to have been more or less washed away. Professor Brewer, who ascended the highest of these old volcanoes, noticed several blocks of granite near the summit and within its crater mixed with the ashes. This

* The position of the most important of these moraines will be found laid down on the southeast-quarter sheet of the Central California Map of the State Geological Survey.

might seem, at first sight, as if indicative of the fact that the glacier came down the northeast slope of Mount Ritter. This would be hardly possible, however, for the position of the moraines to the south does not indicate that the glacier ever rose as high as this; and, indeed, so great a thickness of the ice, at so low a level as 7,000 feet, on the eastern slope, would not be in harmony with what has been elsewhere observed in this region. Besides, it seems impossible that glaciers should have passed over those cones of easily movable ashes without spoiling their symmetry, which has certainly not been accomplished. The advocates of the excessive erosive power of moving ice certainly could not admit that these cones have ever stood in the path of a glacier. It is not impossible that the granite should have been thrown up from below by volcanic forces. Certainly everywhere in the Sierra lava and ashes have been projected in astonishing quantity through this rock, and it would not appear that any positive reason can be given why some portions of the underlying granite should not have come to the surface with the purely volcanic materials.

As a general rule these morainic accumulations on the eastern slope of the Sierra are massive and extremely well marked. They extend out a few miles from the edge of the mountains, and then come at once to a stop, the position of their terminal point being as easy as possible to fix.

In the gorge leading down from the Mono Pass, which is 10,765 feet in elevation, there are abundant evidences of former glaciers, from near the summit to the very foot of the cañon. The rocks are rounded, polished, and grooved, and from the bottom of the mountain large piles of detrital materials extend out into the plain for several miles. According to Mr. King, the lower portions of these moraines exhibit distinct traces of terraces, indicating that at the time of the accumulation of these piles of detrital materials Mono Lake stood at a much higher level than it now does. This condition of things has received abundant confirmation from other facts observed all through the region east of the crest of the Sierra Nevada. Unfortunately, barometric observations were not taken along the base of these moraines, so that the precise altitude of their termini above the sea, or above Mono Lake, is not known; the position of the terraces immediately upon the shores of that lake, however, show it to have been, at one time, at least 600 feet higher than it now is.

All through the region at the head of the Tuolumne River the perfection with which the moraines are preserved was, for the party exploring that portion of the Sierra, a constant theme of remark. Not less striking was the polish of the rock surfaces, which often, when struck by the sunlight at the right angle, glittered in the distance like mirrors. In crossing from Tenaya Lake to Soda Springs the rocks for long stretches were bare, and so smooth that the mules could with difficulty keep their footing. The fact was repeatedly noticed, all through this region, that where a great thickness of ice had formerly rested on the granite, which is almost the only formation of this glaciated region, the surface of the rock seems to have undergone a molecular change, a sort of crust having been formed, as if by the crushing and compacting together of the crystalline minerals of which the granite is made up. This crust appears to be more durable than the body of the rock; and, in the process of weathering, the exterior sometimes scales off in plates or flakes, half an inch thick or more, of which one side is as nicely polished as if the work had been done only yesterday. Other portions of the granite which have not been subjected to this pressure seem to be eroded with comparative rapidity, and their surfaces are often quite irregularly worn out in cavities. Professor Brewer thought that he observed this peculiar change of the crust of the granite to be strikingly developed in certain portions of the Mono Pass, where the glacier had been forced to make its way through narrow gorges, and where, in consequence, the pressure exercised on the enclosing rocky walls must have been enormous.

The locality farthest north in the Sierra where any extensive proofs of former glaciation have been discovered, — so far as known to the writer, — on the eastern slope of the range, is at a point about ten miles northwest of Mono Lake. Here, at the head of Walker River, and between Castle Peak and the Tower Peak Range, is a depression in the Sierra over which crosses the so-called Virginia Trail, once considerably used as connecting the Upper Tuolumne and Merced rivers with Aurora and the mining districts of Nevada.

This trail crosses to the southeast of Castle Peak; but Green River, which heads at the summit of the pass, finds its way down the eastern slope on the northwest side of this mountain, which is nearly 12,000 feet high. In the cañon of this stream a very large glacier once descended almost to the level of the Big Meadows. The moraines left by it are very large and distinct, forming two parallel ridges, some 350 feet in height, made up of the usual angular débris of the range above. It was noticed by the writer, how much these moraines resembled, both in form and size, the detrital accumulations of similar origin in the Upper Arkansas Valley. It was also remarked that here, as in most cases in the Rocky Mountains, the lateral moraines high up in the range seem to have been almost entirely obliterated, while those low down, on the nearly level valley, at the base of the mountains, are not only of immense size, but perfectly preserved in form.

Passing to the north of the Tuolumne River, we find a very considerable change in the topography of the Sierra, accompanied by a rapid decline in its altitude. These altered conditions make themselves manifest at once in the character of the traces of former glaciation which are discoverable. There are no more such immense ancient glacial systems as those of the King's and Tuolumne rivers, which rival with or even surpass the largest ice-flows at present existing in the Alps. This is as we should expect, for the traces of former glaciers are everywhere in the Sierra Nevada found to be in strict harmony with its present climatic and topographic features. From the head of the Tuolumne north there is no longer one almost unbroken western slope to the range, with an extremely rapid descent on the east into a deep valley, separating the Sierra Nevada most distinctly from the Great Basin ranges; the mass becomes more and more split up into subordinate parts by spurs making off to the north and inosculating with still more easterly ranges, so that any line of division between them must be largely artificial. Finally, when we reach Plumas County we have several nearly parallel ranges of about equal elevation, enclosing extensive valleys, where, however, the elevation is not great enough to have given rise to large glaciers, and where the diminished precipitation also makes their former existence less probable.

Another circumstance renders the conditions of the northern portion of the Sierra less favorable than they are farther south for the observation of the traces of former glaciation. The farther we go north the more the higher portions of the range become covered with volcanic materials, which are almost entirely wanting about the upper basins of the large rivers of the High Sierra. These volcanic rocks are not favorable either for receiving or retaining glacial striation or polish.

The next stream of importance, north of the Tuolumne, is the Stanislaus, and the range of the Sierra at its head is still quite high, the Sonora Pass, which leads from the head-waters of the Stanislaus to those of the West-Walker River, being about 10,000 feet above the sea-level. But glacial markings were not seen on the eastern slope of the pass at a distance from the summit of over two miles. Above that they were abundant, and they were also seen high up on the elevated ridges south, which rise to an altitude of nearly 12,000 feet above the sea-level. The spurs between the branches of the Stanislaus, for a considerable distance below the summit, exhibit indications of the former existence of masses of ice of great thickness. Professor Brewer's notes give the following particulars in regard to these occurrences, obtained in his examinations along the Sonora Pass road, in 1863: "We camped at the lower crossing of the Stanislaus, about eighteen miles west of the summit, and examined the hills south. The sides of the cañon rise abruptly to the height of 2,500 or 3,000 feet. Granite extends to within perhaps 700 feet of the highest point reached, which was of volcanic, rudely columnar. Higher mountains are on every side, mostly of granite, capped with lava. On the ridges lying between the forks of the Stanislaus, north of us, these were exceedingly grand, rising perhaps 3,500 feet above the river. Their tops were worn into fantastic forms; one was not unlike an immense castle crowning the bold mountain. The rock of the spur or ridge reached was of porphyritic lava, rather soft. Perched near the top were ten or twelve large granite boulders, which must have been deposited by ice, since they could not possibly have been carried there by water. They were of coarse texture, the feldspar crystals very large, some angular, others rounded and weathered. One of these, perched on a very sharp ridge, measured seventeen feet long, fourteen wide, and twelve high; the others were smaller. Another lava spur, a fourth of a mile east, had its top strewn with similar boulders. These must have come from the east, where at the distance of three or four miles there is granite at a greater elevation than that of these boulders, and they must have been brought by glaciers that flowed from the higher mountains down the cañon of the Stanislaus River. No glacial polishings were observed, but the rock is not well calculated to preserve them." Nothing indicating the passage of glaciers was observed farther down the Stanislaus Valley. The road descended at a considerable height above the river, the bed of which was examined by the writer, at a point near the Sugar Pine mining district, and no signs of glaciation found. This, however, was at a level probably considerably below the point to which the former glacier reached at the time of its greatest extension.

At a still lower level, namely, of about 2,200 feet, between Sonora and Columbia, several square miles of the surface of the limestone rock have been cleared of the overlying detritus by those engaged in washing for gold. Nowhere can a trace of the former existence of glaciers in this region be discovered. Indeed, there is not a locality in the Sierra where any proof whatever has been obtained that the ice descended, even in the most favorable positions, to a point as low as 2,000 feet above the sea-level. And a large extent of rock-surface has been exposed, all through the auriferous belt, by the various and extensive mining operations there carried on.

The Mokelumne River heads in a group of high peaks six miles south of Silver Mountain; the eastern slope is drained in this part of the range by the head-waters of the Carson. Numerous branches of the South Fork of the American River take their rise in the northwestern slopes of the spurs whose opposite sides drain into the Mokelumne. The Cosumnes River, which runs into the Sacramento between the Mokelumne and the American, does not head so far up as the summit range of the Sierra. This stream need not, therefore, be taken into consideration in describing the former glaciation of the region. The Mokelumne, also, is of little importance in this connection; for, although its sources drain an elevated district, there are no important affluents coming into it at high altitudes, so that there was no chance for the formation of a large glacier at its head. The lowest point in this region at which evidences of the former presence of ice were detected was Silver Valley, 7,300 feet above the sea-level. This locality is in the Stanislaus Valley, about twenty-two miles from the Calaveras Big Trees, on the road to Silver Mountain. At Hermit Valley, on the Mokelumne, at an altitude of 7,259 feet, distinct marks of glacial action were met with, and from this point they continued to be observed in abundance almost up to the very summit of the pass, the height of which is nearly 9,000 feet above the sea-level. No extensive moraines were seen; but it can hardly be doubted that a sufficient amount of detailed exploration in this region would make it possible to lay down the ancient limits of the ice with considerable approach to accuracy. The thickness of the mass must have been great in this region, just in the vicinity of the summit, for large blocks of granite may be seen on the crest of a ridge, about 300 feet high, a little south of the pass, resting on the lava in a position such as they could not have taken without the help of ice. As already suggested, in regions like this, where friable and easily disintegrated volcanic rocks abound, the amount of erosion which has taken place since the melting away of the ice is quite considerable, rendering it difficult to connect the isolated occurrences of transported material without a careful survey and an accurate map. Traces of former glaciation were observed in abundance on the eastern slope, nearly down to Silver Mountain City, 6,516 feet above the sea-level. Just below that mining settlement volcanic rocks cover the surface, and no more striation was noticed. It is probable, however, that the glacier descended considerably lower on this side, for numerous blocks of granite were seen perched high up on the sides of the lava-covered ridges, where they must have been left by ice.

The western slope of the Sierra, from Carson Pass nearly to Donner Pass, or the crossing of the Central Pacific Railroad, a distance of about fifty miles, is drained by the numerous branches of the American River. For a considerable portion of this distance the summit of the Sierra is divided into two nearly parallel ranges of about equal height, and between them lies by far the largest and most important mountain lake of California, Lake Tahoe, which is about twenty-one miles long, and from nine to twelve in breadth. The elevation of the range on the west side of this lake, in its highest point, a little exceeds 9,000 feet. Pyramid Peak, ten miles southwest of the south end of Lake Tahoe, and just north of the Placerville road to Carson Valley, which ascends the South Fork of the American, is the highest point north of Silver Mountain until we reach Lassen's Peak, having an elevation of about 10,100 feet, which is nearly 500 feet less than the last-named summit. The other prominent points along the range at the head of the American River are nearly a thousand feet lower than Pyramid Peak.* Mount Stanford, just north of Donner Pass, is 9,102 feet in elevation. Of the passes along the range between this point and Pyramid Peak the highest is that of Squaw Valley, crossed by a trail only, and 8,774 feet in elevation; the pass traversed by the Central Pacific Railroad is only 7,017 feet above the sea-level.

The point farthest south in the American River basin where traces of former glaciation have been noticed by the Geological Survey is at Silver Lake, near Carson Pass, at the head of Alpine Creek, one of the branches of the South Fork of the American. In fact, the region all about the Carson Pass, which has nearly the same elevation as the Silver Mountain Pass, exhibits abundant proofs of the former presence of glaciers. Near Tragedy Springs boulders of granite were seen resting on the lava tables, as if left there by ice, although the striation was wanting.

Farther north, all about Hope Valley, and around a small lake in Luther's Pass, which connects with the Johnson Pass, are abundant glacial traces.

* See Table of Barometric Altitudes, in Appendix to the gravel volume.

Around Pyramid Peak extensive ice-flows have existed in former times. The rock of this lofty peak is all granite, which about the summit covers the surface in large angular blocks. On the east side is a valley with much bare rock, which is polished by glaciers, and contains several small lakes. The large ice-flow which formed on this slope descended to the south, and passed over a high precipice into the cañon of the American River, a short distance above Slippery Ford. The name of the latter locality is suggestive of the glacier-polished surface of the rock at the crossing of the stream.

From Pyramid Peak the range extends in a nearly northerly direction for about twelve miles, and in the gorges between the spurs leading down from it to Lake Tahoe glaciers formerly descended, probably nearly or quite to the level of that fine sheet of water, which is about 6,250 feet in altitude. There is also a high and somewhat isolated point, called Crystal Peak, five miles north-northeast of Pyramid Peak and at the head of Fallen Leaf Lake, which also sent down its glaciers to the east and north. In this part of the range, which runs straight north from Pyramid Peak, a large branch of the Middle Fork of the American River heads, running northwest and joining the main stream at Big Meadows. This branch is called the Rubicon, and its valley is polished and striated throughout its whole length. The Little Rubicon, a much smaller stream, running nearly parallel with the last-mentioned, exhibits similar features. According to Mr. Bowman, who made a detailed survey of this region for the California Water Company, the lowest point at which he observed glacial gravel in the course of his work around the region drained by the Middle Fork of the American was a little below Forney's, or Pilot Creek, at an altitude of about 5,000 feet above the sea-level.

From Burton Pass the main divide of the Sierra trends a little more to the west of north, and is quite distinctly marked as far north as Mount Stanford, although declining gradually in elevation. The Twin Peaks and Granite Chief are two prominent points in this division of the range; the former has an elevation of 8,724, the latter of 9,144 feet above the sea. Some of the higher portions of the ridge are capped with tables of lava, irregularly eroded away, as is so common an occurrence everywhere in the range from the Sonora Pass northward. Glaciers, no doubt, made their way down both sides of this portion of the range. Quite an extensive one must have descended in the valley of the North Fork; but the upper portion of this stream has been very little examined by the Survey.

Bear River, on the other hand, being near the line of the Central Pacific railroad, which runs on the divide between that stream and the North Fork of the American, has been pretty thoroughly explored, and the evidences of former glacial action traced down to a little below Emigrant Gap, 5,521 feet above the sea. On the mountain immediately north of Summit Station, at a point 7,722 feet above the sea, a glacially scratched and polished surface was observed, indicating that the ice-mass was here not less than 700 feet in thickness. From the summit down the valley old moraines may be seen high above its bottom, along the top of which, or near it, the railroad occasionally passes for some distance. At Sereno Lake, where ice is cut for the supply of the railroad company, the moraine, there very distinctly marked, was about 400 feet above Summit Valley. Near Emigrant Gap the road is built on the southerly and southeasterly flank of an old moraine of great size. The top of this is from one to three hundred feet above the line of the track, the slope descending some 300 feet or more, and in places as much as 500 feet, to the bottom of the nearest depression, called Wilson's Ravine. The upper portion of the ridge is thickly dotted with granite and lava boulders as far down as Sailor Ravine, about three miles by the track below Emigrant Gap. Professor Pettee remarks in his notes of this region as follows: "It was at the head of this ravine, a quarter of a mile from the track, that I saw the last granite boulder on this trip. Later in the season I started from Blue Cañon Station, and found a single piece of granite about half a mile farther down than Sailor Ravine, at a point nearly due east from the Blue Cañon Station, at an altitude of 5,081 feet. That is the lowest point at which I saw evidences of the remnants of glacial action. On the opposite side of Bear River, two miles to the northwest of the railroad line, there is a considerable moraine extending down to a probably somewhat lower level than that just described. But there is no information as to the precise point to which it descended."

A large extent of country, somewhat lower down on the slope of the Sierra than that which has already been noticed, was explored by Mr. Goodyear, as detailed in the preceding pages.* His field of work lay chiefly between the South Fork of the North Fork and the Middle Fork of the Middle Fork of the American River; at least, it was only in the part of the Sierra between these two streams that he in the course of his explorations

* For details of the route passed over by Mr. Goodyear in the course of his explorations, see page 82, and accompanying diagram, Plate B. in the gravel volume.

reached an altitude great enough to warrant the expectation that traces of former glaciation might be met with. The most elevated region examined by Mr. Goodyear was about the head of the North Fork of the Middle Fork of the American, where he made several barometric observations at stations between 5,000 and 7,000 feet above the sea-level. The highest point reached was Bald Mountain, with an altitude of 7,091 feet.* This region lies south of the Central Pacific railroad, and nearly west of the upper part of Lake Tahoe. In spite of its great altitude, however, Mr. Goodyear's notes do not mention any glacial scratches or polished surfaces as existing in the region explored by him. A large portion of this district, it is true, is covered with volcanic débris; but the valleys are mostly cut down deep into the granite or slate; and the rock would in many places have been of a texture and hardness favorable to the preservation of glacial markings. This is especially the case in the vicinity of the Canada Hill and Bald Mountain Range, where a kind of quartz-rock predominates, which may be presumed to have had all the qualities necessary for retaining either striations or polished surfaces. The reason why the glacier descended to so much lower altitudes on the line of the railroad, as mentioned above, must have been that there was a more extensive gathering-ground for the glacial mass, at a high altitude, in the upper basin of the North Fork than there was at the head of those branches of the Middle Fork which chiefly drain the region explored by Mr. Goodyear.

From Bear River north no indications have ever been observed, by any member of the Geological Corps, of extensive glaciation. During the continuance of the Survey, Sierra County was but very hastily and imperfectly explored, and the higher part of it was not visited at all. Plumas County, however, was examined with some care by the writer, during the summer of 1866, from Quincy to Lassen's Peak, which forms the extreme northwest corner of the county. Nowhere in the course of this exploration were any clearly defined traces of former glaciation observed, in spite of the very considerable elevation of the valleys and the surrounding ranges. Even the higher latitude seems not to have been efficient in aiding to bring about in this part of the Sierra those climatological conditions necessary to the formation of glaciers of importance.

During the summer and autumn of 1879 the higher portions of Sierra and Plumas counties were explored by Professor Pettee, as already mentioned,

* See Table of Barometric Altitudes, appended to gravel volume.

and traces of former glaciation of the region were carefully sought for by him. He reports as follows in reference to this point: —

"On the divide between the South and Middle Yubas I saw distinct markings and polishings of the granite rocks near the Bowman reservoir, at an altitude of about 5,500 feet. No time, however, was taken for any detailed examination of this region. The markings seen were all near the reservoir in the cañon; no note was made of their direction. On the divide between the Middle and North Yubas, I saw glacial markings on granite near the head-waters of the North Yuba, at a point about six miles above Sierra City, and at an altitude of about 5,800 feet. The locality is near the Blue Gravel location, on Milton Creek, one of the head-waters of the North Yuba. The amount of bed-rock uncovered was not large, but the parallel striæ were exceedingly distinct. Their course was northwest and southeast, bearing directly for the highest visible point of the Sierra Buttes, about six or eight miles distant. To the north of the North Yuba I frequently reached altitudes sufficiently great for glacial markings; but I saw no exposed bed-rock which showed signs of being scored and polished. Erratic boulders, difficult to account for except on the theory of glacial transportation, were seen near La Porte and Howland Flat. And similarly, near Forest City, south of Downieville, on the other divide, there were peculiar boulders quite different from those which made up the mass of the surface débris. The altitude at which these last were found was a little less than 5,000 feet; of the former, about 5,200. At Jamison City, the altitude of which is about 5,000 feet, to the northeast of Eureka Peak and the Plumas Eureka quartz-mine, there is a remarkable deposit of heavy gravel and boulders, none of which are very much rounded, while some are quite angular. The deposit is a portion of an extensive range of similar materials, which is said to be traceable for several miles along the upper course of the Feather River, towards Mohawk and Sierra Valleys. Upon the surface of the gravel there are numerous erratic boulders, as much as ten or fifteen feet in diameter, different in character from the main mass of the gravel. When exposed to view, a section of the gravel frequently showed a morainic structure. I was inclined to the view that the glaciers had considerable to do with the formation of this deposit, but I could find no further corroborative evidence. The day after I left Jamison City a heavy snow-storm set in, which prevented my pushing inquiries any further in that direction. The region to the north and northwest of the Sierra Buttes — forming the divide between the

Feather and the Yuba drainage — is one which, in all probability, has been materially modified by glacial agencies; but it needs to be visited earlier in the season. The snow shut me out from it during the first week of October."

In spite of the very considerable elevation of Lassen's Peak (10,577 feet), no evidences of former glaciation were obtained in its vicinity either by Professor Brewer and party in 1863, or by the writer some years later. It is quite likely, however, that more careful observations might show the existence near this peak of traces of detrital material which could be accepted as evidences of former glaciation. The character of the rock formations for some distance around this volcanic mass is not at all suited to the preservation of striated surfaces.

Somewhat similar remarks might be made about the region adjacent to the south slope of Mount Shasta. Neither there nor in the valley of the Upper Sacramento, nor in the elevated plain in the neighborhood of Yreka, on the northwest of this great volcanic mass, were any evidences of former glaciation observed by the writer. Mr. King, however, in exploring the north side of the cone, not only discovered active glaciers, but proof that they had formerly been much larger than they now are. In his account of these discoveries, to which reference has already been made, Mr. King remarks as follows: "One of the most interesting of all the features of the country was, however, the clearly defined moraines of the ancient and more widely extended glacier system. Nearly the whole topography of the lower part of the cone is modified by the deposition of glacial material. At an elevation of about 8,000 feet on the southern or snowless side of the mountain is a great plateau-like terrace, about 2,500 or 3,000 feet wide, extending around one half of the cone, and composed wholly of moraine material. Besides these, long, straight, or slightly curved medial moraines jut out from the mountain in all directions, not unfrequently descending into the valley for several miles."

This ends what there is to be said in regard to the traces of the former glaciation of the Sierra Nevada, as nothing more of this kind has been observed until we pass to the north of the California line. Not even in the high ranges of Trinity and Klamath counties was anything seen which would justify the belief that these mountains, so near the coast, had ever been covered with ice. Before discussing what has been stated in reference to the glaciation of regions still farther north, it will be desirable to briefly state what is known in regard to the former glaciers of the ranges east of the Sierra Nevada, in the same latitude, and also in the Rocky Mountains.

At the time of the beginning of the California Geological Survey (1860), nothing whatever was known, at least nothing had been published, in regard to the former presence of glaciers anywhere in the Rocky Mountains. Our investigations having made it evident that ice had once covered a considerable portion of the Sierra Nevada, and having clearly established the most important facts connected with this former glaciation along the Pacific coast as far north as the United States boundary line, it became desirable that something should be ascertained in regard to the occurrence of similar phenomena in portions of the Cordilleras lying farther east, namely, the Great Basin Ranges and the Rocky Mountains. Up to the year 1869 nothing had been definitely made out as to the former glaciation of any part of the Cordilleras outside of the limits of California.* It was, therefore, partly for the purpose of obtaining some light on this interesting question that the writer spent a part of the summer in the highest region of the Rocky Mountains, as already mentioned. Previous to this, however, he had personally examined several of the important ranges of the Great Basin, namely, the West Humboldt, the Toyabe, and portions of the Wahsatch Range. Since 1869, the voluminous publications of the Fortieth Parallel and the other United States Surveys have given abundant details in regard to the now well-understood phenomena of extinct glaciers in the region in question, and it is now possible to make out pretty clearly what portions of the ranges were formerly covered by ice, and how far down their flanks the detrital materials have been carried by glacial agencies. The deficiencies in our knowledge are most marked in the northern portion of the Rocky Mountain ranges within the limits of the United States. Much the larger portion of the detailed work done by authority of the United States has been carried on in the central and southern parts of the region in question, or to the south of the parallel of 42°. The belt of country thus examined, however, includes the higher ranges of the Cordilleras, whose broadest and highest portion lies between the parallels of 36° 30′ and 42°.

* From Dr. Hayden's "Report of the Exploration of the Yellowstone and Missouri Rivers" (1859–60), published in 1869, it would appear that the fact of the detrital material in the Wind River Mountains having everywhere been derived from rocks near at hand had strongly impressed itself on the author's mind. And when it is said (page 84) that, "on the left bank of Wind River, it would seem as though the icebergs had lodged against it and quietly deposited the burden of rocks which they had acquired in the more elevated mountains," it is apparent that the intention of the author is to indicate the existence of moraines, and to describe those phenomena which could only have been due to former glaciation.

The general result of all these explorations is the same as that so clearly established in California, — namely, that comparatively only a very small portion of the highest ranges of mountains which stretch across that vast region has ever been covered with glaciers; and, furthermore, as a necessary consequence of this, that there has never been, in this region, anything like a Northern Drift period, or a transportation of material in any general direction, independent of the present topographical features of the country.

No traces of former glaciers have been observed in any of the ranges of Western Nevada, so far as known to the writer. The West Humboldt Range, the culminating point of which, Star Peak, is 9,925 feet above the sea-level, shows no signs of former glaciation. In the East Humboldt Range, on the other hand, the ice-fields were once of considerable size, as reported by Messrs. Emmons and Hague.* The commanding point of this range is Mount Bonpland, which has a height of 11,321 feet, several other points reaching over 10,000 feet. According to the authority quoted, the summits of the East Humboldt Range, from White Cloud Peak to the northern end, all show abundant evidences of glaciation. In the cañon of the south branch of the South Fork of the Humboldt River the glacier was eight miles long. Fifty miles of the range present a pretty continuous area of glaciated surfaces.

The Wahsatch Mountains also furnish abundant evidences of former glaciers, but only in their higher portions. According to Messrs. Emmons and Hague, such traces are most conspicuous in the Cottonwood region, or that part of the Wahsatch Range which is included between Utah Lake and Emigration Cañon, where the mountain mass is about fifteen miles in width and over 10,000 feet in average height, the highest point, Clayton's Peak, reaching an elevation of 11,889 feet. From this dominating peak the main system of glaciers radiated out, as shown by the topography, as well as by moraines and the shapes of the cañons. Most of these glaciers, however, did not descend to a very low level; but that of Little Cottonwood is thought to have extended down to the shore of the ancient lake which once filled the Utah Basin.

There appear also to be some evidences of former glaciers on the Uinta Range; but, as far as can be judged from the published descriptions of that region, the area covered by them was not extensive. Messrs. Emmons and Hague speak† of shallow mountain lakes, occupying glacier-worn basins in

* Fortieth Parallel Survey, Vol. III. Descriptive Geology, pp. 533, 537.

† l. c., p. 312.

an amphitheatre lying between Bald Mountain and Mount Agassiz. The average height of the basin is 10,000 feet, and the altitude of the two peaks named respectively 11,977 and 13,000 feet.

Farther east, in the Rocky Mountains proper, the character and extent of the former glaciation of the ranges is now pretty well understood, chiefly owing to the labors of the Geological Survey, under Dr. Hayden's direction. The entire aspect of the conditions closely resembles that furnished by California; everywhere in the highest ranges, under favorable topographical conditions, glaciers have formerly existed, and have extended down the slopes of the mountains in the cañons to very considerable distances. Although they have now entirely disappeared, with the single exception already noted in the Wind River Range, they have left behind them abundant proofs of their past existence in the usual form of moraines, polished and striated surfaces, and *roches moutonnées*, similar to those already described as occurring so extensively in the Sierra Nevada. As in that range, so in the Rocky Mountains, these remains of the work of former glaciers exist, not only on a grand scale, but in the greatest perfection; so that, to the eye of the experienced observer, there can be no mistake about the nature of the phenomena. There need be no difficulty in separating the results of aqueous from those of glacial erosion, and no reason why, in time, the precise limits of the area formerly covered by ice should not be laid down on the map, just as is now doing for the Swiss Alps.

At present the northern portion of the Cordilleras is that in regard to which definite information is most to be desired. The ranges, as a whole, decidedly diminish in altitude in that direction; but this falling-off is, to some extent, compensated by the increased latitude.

In the region of South Park, and especially in the Upper Arkansas Valley, the glacial features are perhaps more striking than anywhere else in the Rocky Mountains. From all the cañons of the Sawatch Range, on the west side of the head of the Arkansas, large glaciers came down, and have left great morainic accumulations, which extend across the valley in long parallel lines several hundred feet high. The most conspicuous of these moraines are those bordering Pine, Clear, and Lake Creeks. The Twin Lakes, nearly at the head of the valley, are enclosed between detrital piles of which the glacial origin cannot be mistaken. The highest adjacent summits on the west are a little over 14,000 feet in height, the Sawatch being the most elevated range of the Rocky Mountains; hence the great development of the glaciers. These, however, did not descend anywhere in this region to nearly as low a point as was reached by several of the Californian glaciers. The upper part of the Arkansas Valley is about 9,000 feet above the sea-level, and there is no proof that it was ever occupied by ice. Indeed, the whole series of glacial phenomena in this part of the Rocky Mountains is consistent with itself throughout; only the highest summits and the most elevated valleys were occupied by the ice. For instance, at the head of South Park, at an elevation of nearly 10,000 feet, just above Fairplay, the valley of the Middle Fork of the South Platte is barred across by an immense terminal moraine, 150 feet high, above which was once a large lake, but which has since been drained off by the cutting through of the detrital mass, the material of which has been carried down and spread over the valley below by the rush of water. Nowhere below this point could any traces of glaciation be discovered over the whole area of the Park; while above the moraine, in all the adjacent higher side-valleys and cañons, such indications were extremely conspicuous. The topographical features of the range above Fairplay were highly favorable to the formation of an immense glacier; hence the united stream of ice coming down this branch of the Platte was nearly or quite equal to the largest of those formed on the eastern declivity of the Sawatch Range, the breadth and height of which furnished all the necessary conditions for the accumulation of glaciers of the largest dimensions. Whether the western slope of the Sawatch Mountains was as favorably situated as the eastern, in this respect, the writer is unable to state from personal observation. On the geological map of Colorado, published under the direction of Professor Hayden, a large moraine is indicated as having its origin in the cañon between Mounts Harvard and Yale, and descending to the west, terminating at an altitude of about 9,500 feet. No other moraines are shown on the map in any of the ranges directly west of the Sawatch. To the southwest of this, however, there are several. A small area is indicated as covered by morainic débris at a locality on the head-waters of Vallecito Creek, northwest of Mount Oso (13,640 feet). Another is shown at the head of the Lake Fork of the Gunnison, in latitude 37° 56′, at about 9,000 feet in elevation. Besides these minor glaciated areas, there are two others of more importance: one of these is near the sources of the Rio Piedra, south of Weeminucke Pass, on the southwest side of the San Juan Mountains, in latitude 37° 30′; the other at the head of Rio Chama, in latitude 37°. These two last mentioned, which are of interest, since they appear to be the most southern indications of former glaciation seen in the Rocky Mountains, have been described somewhat in detail by Mr. F. M. Endlich.*

The Weeminucke glacier is indicated, on a sketch-map accompanying the article cited, as having had a length of five or six miles, and there was a smaller one parallel with it on the northeast, which came down the Huerto branch of the Rio Piedra. These appear to have descended to about the same level, — 8,000 feet above the sea. Mr. Endlich describes the glacier of the Rio Chama as having been of much greater extent than those just mentioned. It occupied a position on the summit of the volcanic plateau, at the head-waters of Rio Conejos and Rio Chama. In the ascent of the latter river the first indications of former glacial activity were met with at an altitude of 8,450 feet. On the volcanic plateau above, at an elevation of about 11,800 feet, and higher up for four miles farther north, the rocks are beautifully striated and polished. The length of the ancient glacier is indicated on the general map of Colorado as about eight miles. Mr. Endlich says that more than twenty-five square miles must have been covered on the plateau by this extensive mass of ice, which appears to have been chiefly developed at an elevation of about 12,000 feet, and to have descended to about 8,000 feet above the sea-level. The above-mentioned occurrences, and some "small indications of local glacial action" observed in some of the cañons of the Sangre de Cristo Range, of which Mr. Endlich remarks "that there is no certainty as to their true glacial character," are said by him to include all the undoubted glacial regions of Southern Colorado that he had occasion to visit during 1874 and 1875, which were the years when the work was being carried on in that region. At all events, they are the only ones indicated on the final map published by the Survey.

Although the geological maps of Colorado, published under Dr. Hayden's direction, do not indicate the existence of any moraines along the eastern slope of the so-called Front Range, or that portion of the chain which faces the Plains, yet there are occasional references in the published Reports to evidences of former glacial action in this part of the Rocky Mountains. A detachment of the party taken to Colorado by the writer, in 1869, explored the vicinity of Gray's Peak, which is in latitude 39° 38′, and 14,341 feet above the sea-level. They also followed down Clear Creek to the level of the Plains at the base of the range. Professor Brewer conducted this sub-

* In Report of U. S. Geological and Geographical Survey for 1875, p. 206, under the head of "Ancient Glaciers in Southern Colorado."

party, and his notes make frequent reference to glacial phenomena observed along the route. At the base of Gray's Peak distinctly preserved moraines were observed, but no striations or polished surfaces. Farther down the indication of the former passage of a glacier through the cañon were abundant. Between Brown's Mills and Georgetown the rocks in the bottom of the valley are finely polished, and the projecting ledges rounded and smoothed; there were also occasional evidences of moraines, although not especially marked in character. The following passage is quoted from Professor Brewer's notes: "Some few glacial traces were observed for the first few miles below Georgetown [elevation, 8,412 feet], but we saw none whatever below Idaho [7,535 feet]. For most of the distance [from Idaho to the Plains] it was impossible that any considerable glacier should ever have passed down that portion of the valley since it had its present features. Frequent jagged outliers at short turns in the valley showed that no glaciers could ever have passed them and left them in their present shape; in fact, but meagre traces were found below Georgetown, and these only for the first five or six miles."

Farther north, about latitude 40° 15', in the Middle Park region, Mr. A. R. Marvine has indicated the existence of large moraines and other proofs of former glaciers. The locality is near Grand Lake, in the valley of the North Fork of Grand River, between the southern end of the Medicine Bow Range on the west and the Long's Peak Group on the east. The elevation of the lake is 8,153 feet, and the moraines do not appear to have descended much, if any, below this level. There are also proofs of the former existence of a glacier of moderate size, which came down the valley of the East Fork of the same river, which takes its rise between Mount Audubon (13,173 feet) and Arapahoe Peak (13,520 feet).

The phenomena of glaciation in the ranges which enclose the North Park and extend beyond it to the north as far as the parallel of 42° have been briefly indicated by Mr. A. Hague.* The Medicine Bow Mountains extend from latitude 40° 15' to 41° 40', having an approximate northwest trend. The western side of this range shuts in the North Park on the east and north, and still farther northward forms the boundary of the North Platte Valley, which lies between it and the Park Range. As thus defined, the Medicine Bow Range is about a hundred miles in length. Its highest summits a little exceed 13,000 feet in elevation. All the more elevated regions

* See Report of Fortieth Parallel Survey, Vol. II. p. 96, for the Medicine Bow Range, and p. 131 for the Park Range.

of this range exhibit well-marked evidences of glacial action. The summits of the main peaks are everywhere worn in a manner which shows unmistakable signs of ice-erosion, and glacial boulders and detrital matter cover the lesser depressions and slopes. In the region of Medicine Peak (height 12,231 feet), glaciers occupied all the upper valleys. The lowest elevation reached by these is not expressly stated by Mr. Hague. Near the parallel of 41° the range has its maximum width of twenty-five miles, and there two well-defined ridges are developed, the culminating points of which are Clark's Peak (13,167 feet) and Medicine Peak (12,231 feet). Between these is a high plateau, nearly 10,000 feet above the sea-level, which is said to be gently undulating, and without any marked topographical features. It may, therefore, be inferred that the glaciers did not extend down as low as this.

In the Park Range, also, of which the highest summits reach an altitude of a little over 12,000 feet (Mount Zirkel, 12,426 feet, Ethel Peak, 11,976 feet), the traces of former glacial action are abundant "through most of the higher mountain regions." Mr. Hague notices a fact, which has also frequently impressed itself on the attention of the writer, namely, the great size of the terminal moraines as compared with the length of the glacier itself. In speaking of the Park Range, he remarks: "These valleys are never more than three or four miles in length, and at their mouth, considering the limited size of the ancient glaciers, are found immense terminal moraines, which have undergone but little erosion in post-glacial times. It is as if the entire former contents of the cañon had been carried down and dumped at the entrance, and had never been disturbed."

In following the Rocky Mountain ranges to the north of the parallel of 42°, in order to make out the character and extent of the former glaciated areas, great difficulties are encountered, as already mentioned, from the want of any satisfactory detailed investigations in that region. The work of the four United States Surveys* has almost exclusively been confined to the southern and southern central portion of the Cordilleras, considerable areas of which have been gone over by two or even three different organizations. An exception to this, however, is found in the case of the Yellowstone Park and vicinity, whose picturesque scenery and most interesting geological features

* The U. S. Geographical and Geological Survey, under Dr. F. V. Hayden; the Fortieth Parallel Survey, under Clarence King; the Wheeler Survey, under the special auspices of the U. S. Engineer Department; and, finally, the so-called Powell Survey, the publications of which have been chiefly ethnographic in character.

have attracted numerous quasi-scientific government expeditions in that direction. The earlier explorations of the Pacific Railroad Surveys were extended through the northern part of the Rocky Mountains, but the published reports give no information in regard to the phenomena of ancient glaciers in that region, which fact may be accounted for partly by the ignorance and inexperience of the observers, and partly on the ground that details of this kind had not at that time attracted much attention in the Far West, the routes of the explorers being almost exclusively limited to the lower valleys; their object was chiefly to get across the country as rapidly and with as little trouble as possible.

Some hints in regard to the existence of former glaciers in the more northern portions of the Rocky Mountains, south of the United States boundary, may be obtained from Dr. Hayden's reports. For instance, the volume giving the results of the explorations of the year 1871, when the Yellowstone region was visited, by way of Fort Hall in Idaho and Fort Ellis in Montana, contains the following quotation, which refers to the vicinity of the range of the Snowy Mountains "forming the great water-shed between two portions of the Yellowstone River," a volcanic range rising to the altitude of from 10,000 to 11,000 feet above the sea-level. Here Dr. Hayden describes great detrital accumulations resting against the flanks of the range, and apparently exactly resembling in character the so-called "washes" of the California ranges, of which mention has already been repeatedly made. Of these piles of detritus he says: "The little streams that flow down from the mountain sides cut sections through this deposit, so that they are revealed quite clearly. The upper portion is composed in part of the débris from the mountains, but there is all over the valley a vast deposit of what I can call by no better name than local drift or detritus. In this detritus are quite frequently masses of rock, or boulders, that have evidently been transported a considerable distance by a force not now in operation in this vicinity. This fact points back to a time when we may suppose that there were vast accumulations of snow and ice all over the valleys, but more especially on the sides and summits of the mountains; and as the temperature became much warmer this snow and ice melted, producing rivers and torrents with sufficient force, aided perhaps by the masses of ice, to move these immense boulders from place to place. An important fact should be continually borne in mind, that a critical examination of this detritus reveals no evidence of the existence of rocks from any distant point outside of the river drainage in which they are found; in other words, these superficial deposits are entirely made up of the materials disintegrated from the rocks in the vicinity." *

We have, in the paragraph above quoted, only indirect evidence as to the former existence of glaciers in a part of the elevated region high up on the Yellowstone River near the parallel of 44°. The important point, however, in regard to which the evidence is direct, is, that the detrital material, with which the slopes of the ranges in that region are covered, is all of local origin, as is the case in every other part of the Cordilleras of which mention has been made in the preceding pages.

Although nothing is said in the Report from which the quotation given above was taken about the existence of former glaciers in the region of the Yellowstone Park, the following may be accepted as a strong indication that morainic accumulations of detrital material were intended to be described. In his account of his explorations along the ridge, "in the more immediate valley of the Yellowstone, near the entrance of the East Fork," and not far from the lower end of the Grand Cañon, Dr. Hayden remarks as follows: "What were the forces that wrenched from the parent bed masses of granite, from one ton to five hundred tons weight, rounded off the angles, and lodged them upon the plains 300 to 500 feet above the channels of the principal streams? Along the East Fork, for twenty miles above its mouth, on the west side, there is a sort of terrace [a moraine?] about a mile in width, literally covered with the granite boulders which have been swept down the valley from a short distance above." †

In 1872 the Yellowstone region was again visited by Dr. Hayden's exploring parties, and the Teton Range examined and reported on by Mr. F. H. Bradley. ‡ This range, in which there is a group of three lofty and jagged summits known as the Tetons, lies between the parallels of 43° 30′ and 44°, running nearly north and south along the west side of the head of Snake River. The height of its culminating summit, Mount Hayden, is stated at 13,858 feet. The valley at its base is a little less than 7,000 feet in elevation (mouth of Lewis Fork, 6,870 feet; Jackson's Lake, 6,806 feet). The principal cañons of this range appear, from Mr. Bradley's descriptions, to have been formerly occupied by extensive glaciers. Great moraines are

* Geological Survey of Montana and Adjacent Territories, 1871, p. 55.

† l. c., p. 77.

‡ Report of the U. S. Geological Survey of Montana, Idaho, etc., 1872, pp. 190–271. This appears to be the first Report of Dr. Hayden's in which the words "glacier" and "moraine" occur.

described as coming down into the valley in the vicinity of Jackson's Lake, and this large body of water itself seems to have been formed, if not by the actual damming back of the river by glacial agencies, at least by débris washed down from a series of terminal moraines, now distinctly visible on the western side of the valley, the summit of the higher and outermost being at an altitude of 366 feet above the lake. Jenny's Lake, a little farther south, which lies in the mouth of the Great Cañon of the Teton Range, where is gathered the entire drainage of the western side of the group of the Three Tetons, is also described as a moraine lake, and at other cañons in the range similar bodies of water occur. It is remarked by Mr. Bradley, that in spite of the great size and prominence of the terminal moraines, few remains of lateral ones could be discovered. This fact coincides with what was observed by the writer and party at the head of the South Platte. Another interesting point is, as Mr. Bradley remarks, that "the water in these mountain streams is now so pure as to make it certain that not the least glacial erosion is now going on at any point on the range."

In the preliminary report of the field-work of Dr. Hayden's parties for the season of 1878, the latest published document of that Survey which has come under the writer's notice, it is stated that morainal deposits and glaciated rocks are shown in the Wind River Range, "on a scale such as we have not known in any other portion of the West." It is in these mountains that, as already mentioned, small active glaciers were also discovered by the same party. This range, which occupies, so to speak, the summit of the country, being drained by the head-waters of the Missouri and the Colorado, lies a little farther south than that of the Tetons. It is a very lofty and rugged chain of mountains, but the precise elevation of its dominating summits has not yet been made known; Fremont's Peak, one of the highest of them, was roughly measured by the explorer whose name it bears, and its height given as 13,570 feet.

The Black Hills, lying between the parallels of 43° and 45°, have been explored by a government expedition, to which Professor N. H. Winchell was attached as geologist. The highest point of this range appears to be Harney's Peak; its elevation is given at 9,700 feet. Nothing is said in the official report* of this Survey in regard to past glaciation or the occurrence

* Report of a Reconnaissance of the Black Hills of Dakota, etc., made in the Summer of 1874. By William Ludlow, Captain of Engineers. Washington. 1875.

of drift in these mountains. The descriptions of the surface convey the idea most clearly that all the detrital material is of local origin, and that no part of the surface has ever been covered with ice.

In the preceding pages all that appears to be definitely known in regard to the former glaciation of the surface within the borders of California, and in the Cordilleras south of the United States boundary line, has been placed before the reader; if not with full details, at least with sufficient minuteness to afford a satisfactory basis for a discussion of the phenomena in their connection with other evidences of climatic change.

It will be readily seen that the facts are all of a simple character and entirely in harmony not only with each other, but with the present topographical features of the region included within the field of observation. Briefly resumed, these facts are as follows: In California, the Great Basin, and the Rocky Mountains, up to the head of the Missouri River, the highest portions of the most elevated ranges were formerly covered with glaciers, some of which were very extensive, reaching a development of forty miles, or even more, in length, and of five or six in breadth, — in short, equalling or even surpassing the largest Alpine ice-fields of the present day. These glaciers nowhere descended to within several thousand feet of the sea-level. They show a tendency to descend lower as we proceed northward; but this tendency is, to a considerable degree, nullified by the diminished altitude of the ranges, the highest portion of the Cordilleras lying, in California, between the parallels of 36° and 39°, and widening as it crosses the country, so that its northern limit in the Rocky Mountains is a little beyond the parallel of 44°. No proofs whatever of former glaciation have been detected by competent observers to the south of latitude 36°. All through the region indicated the detrital materials have been carried from the higher toward the lower areas, in strict harmony with the present configuration of the country. A large part of this carrying has been done by water unaided by ice, for the formerly glaciated area occupies but a very small portion of the surface. Where glaciers have existed, there all the signs of their former presence, such as moraines, striated and polished surfaces, and rounded ledges, can be recognized without the slightest difficulty, so that, with accurate maps and careful observations by competent persons, the area formerly covered by ice could, and probably will at some future time, be laid down with the closest approach to accuracy. And, of course, from what has been said above, it will be readily perceived that there is no such thing as "Northern

Drift" anywhere in the region covered by the observations in the preceding pages.

It was after some years of exploration in California and along the Pacific Coast, by the State Geologist and other members of the California Geological Survey, that the writer published, in 1866, the following statement in regard to the absence of the Northern Drift formation from the western coast of North America and from the interior of the continent, throughout the region to the southwest: * —

"The explorations of the Geological Survey of California have demonstrated, however, that there is no true Northern Drift within the limits of this State. Our detrital materials, which often form deposits of great extent and thickness, are invariably found to have been dependent for their origin and present position on causes similar to those now in action, and to have been deposited on the flanks and at the bases of the nearest mountain ranges by currents of water rushing down their slopes. While we have abundant evidence of the former existence of extensive glaciers in the Sierra Nevada, there is no reason to suppose that this ice was to any extent an effective agent in the transportation of the superficial detritus now resting on the flanks of the mountains. The glaciers were confined to the most elevated portions of the ranges, and although the moraines which they have left as evidences of their former extension are often large and conspicuous, they are insignificant in comparison with the detrital masses formed by aqueous erosion. There is nothing anywhere in California which indicates a general glacial epoch, during which ice covered the whole country and moved bodies of detritus over the surface independently of its present configuration, as is seen throughout the Northeastern States.

"The same condition of things prevails in Nevada and through Oregon, as far as explored by the members of the Survey. The detritus seems always to be accumulated at the base of the mountains, — gravel, boulders, and sand lying below and not far distant from the beds of rock of which these materials once formed a part, and from which they appear to have been detached by weathering and aqueous erosion.

"From the observations of Messrs. Ashburner and Dall, it would appear that no evidences of Northern Drift have yet been detected on this coast, even as far north as British Columbia or Russian America. Neither of these gentlemen has observed any indication of a transportation of drift materials

* Proceedings of the California Academy of Sciences, Vol. III. p. 271.

from the north towards the south, or of any condition of things similar to that which must have existed in the Eastern States during the diluvial epoch.

"On examining the published records of explorers in the central portion of the Continent, it will be noticed that there is strong reason to believe that the absence of the Northern Drift formation is not peculiar to the States along the Pacific Coast; but that the whole region west of the Rocky Mountains is also destitute of any indications of a detrital formation moved over the surface in one direction by any great general cause. Judging from our present stock of evidence, I am inclined to draw the line which limits the Northern Drift formation on the south and west approximately from the mouth of the Ohio to the head-waters of the Saskatchewan River."

The above-quoted communication in regard to the character of the drift deposits on the Pacific Coast has been the subject of repeated severe criticisms in various scientific journals at home and in Europe. The subject is an interesting one as bearing directly on a question of much interest, namely, whether the so-called Glacial epoch was of a general, or only of a local character. It is true, however, that this question has not now the importance which it had when the above-quoted communication was made to the California Academy. Since that time it has been clearly established, by extended investigations made in Europe and Asia, that the idea that the phenomena of the drift are due to a general North Polar ice-cap is entirely unsupported by facts, as will be more fully explained further on. Nevertheless, the conditions of the Glacial and Northern Drift epochs in North America are so complicated, that everything which can throw light on the various forms and stages of their development is worthy of a careful setting forth.

As far as California and the mass of the Rocky Mountains south of the immediate vicinity of the United States northern boundary line are concerned, the facts are so clear that there can be no dispute, and need be no discussion, about them. Enough has already been said in the preceding pages on this point, and there is no occasion to alter anything stated in the first of the paragraphs quoted above.

In regard to the former glaciation of Nevada and Oregon, included in the second paragraph, little needs to be added. The condition of things in Nevada has already been set forth, in connection with the other portions of the Great Basin. Nor is there occasion to dwell long on Oregon. That State has been sufficiently examined, both by the writer and by Mr. Gabb, to justify the assertion that the same conditions hold in the Cascade Range as farther south in the Sierra Nevada. There is no such thing as Northern Drift in the State, a very large portion of which is covered by almost bare, horizontal overflows of basaltic lava. As there is no map of the mountains of Oregon approximating even to correctness, it will be impossible to make any more definite statement than this: That the higher points between Mount Pitt and Mount Hood have formerly, in all probability, had each its system of glaciers; but that these could not have been large, because the range is low and the crest narrow, the elevated points being nearly or quite isolated volcanic cones, around which the ice-masses chiefly formed. Dr. Newberry explored the region around the base of the Three Sisters, in latitude 44°, and says, in describing a volcanic cone a little to the south of that group, that the rocks of which it is composed are everywhere cut by deep furrows, which in all cases pointed towards the centre of the mountain mass. Having crossed the main ridge north of the Three Sisters, "the same phenomena were noticed, extending down to the altitude of 4,459 feet, where they terminated in a deep cañon, through which a stream flowed into the Willamette Valley." * The altitude of the loftiest of the group is given by Dr. Newberry at from 10,000 to 11,000 feet; the height of the base from which it rises is not stated, but it appears to be about 5,600 feet. The scratches and furrows on the surface of the volcanic rocks are said to extend down to 2,500 feet below the present snow-line, and everywhere to be directed toward the highest point of the adjacent lofty group of peaks.

If further evidence be needed, it may be found in the latest published work of the author of Frost and Fire, an enthusiastic glacialist, who visited Oregon a few years ago. He says, in speaking of the Cascade Range and the vicinity of Mount Hood, "As for glacial marks, there are none." †

That the present glaciers of Mount Hood were once of considerably larger size than they now are, is vouched for by Mr. A. Hague in the following words: ‡ "One of the most remarkable geological and topographical features of Mount Hood and the vicinity is its very extensive system of extinct glaciers, which everywhere gouged out immense trough-shaped valleys, cutting down deeply into the earlier trachytic lava-flows of the old volcano. The entire network of valleys were all connected with two main glaciers,— that of Hood River on the north, and the Sandy on the south. The ancient

* Report of Pacific Railroad Surveys, Vol. VI. p. 41.

† My Circular Notes, by J. F. Campbell, Vol. I. p. 95.

‡ Am. Journal of Science, Third Series, Vol. I. p. 167.

White River glacier was undoubtedly very large, but, as far as my observations have yet extended, had no tributaries."

Passing across the Columbia River into Washington Territory, we find a condition of things prevailing similar to that which exists farther south. There is no drift other than that which is local in character, as the writer is able to affirm from personal examination. No doubt the ice-masses of the great volcanic cones of that Territory were once larger than they now are; at least, reasoning from analogy, we have every reason to believe that would have been the case. Mr. Emmons, however, in his preliminary report on the exploration of Mount Rainier, to which reference has already been made, makes no mention of any proofs of a former more extensive glaciation in that region.

As far, then, as the second paragraph of the communication made by the writer to the California Academy, in 1866, is concerned, there is no reason whatever for any change in what was said at that time. That there may be evidences that a portion of the country adjacent to Puget Sound has been submerged under the ocean at a not very distant epoch, and that, as a consequence of that submergence, icebergs may have left scattered accumulations of débris in such places, cannot be denied. It is not true, however, that glaciers formerly extended over this region, or that the mass of the detrital material on the surface came from the north.

Passing next to the region north of the boundary of the United States, we have to depend largely on the observations of others, and an attempt will be made to sift the evidence offered, in order to make out whether that part of the Continent presents features of glacial geology essentially different from those existing within our own borders. And for this purpose it will be convenient to begin the proposed examination with the prolongation of the Rocky Mountain ranges in the vicinity and north of the parallel of 49°.

The first authority that one would naturally be inclined to consult is the geologist attached to the Palliser Expedition, which carried on an extensive exploration of the eastern division of the Cordilleras, or the Rocky Mountains proper, during the years 1857 – 1860. Their routes extended over that portion of the mountain system which lies between the parallels of 47° and 53°, or the region drained to the east by the numerous branches of the Saskatchewan and the Athabasca, and to the west chiefly by the Columbia, but also in part by the head-waters of the Fraser. Dr. Hector, the geologist attached to this important expedition, was evidently quite inexperienced, as has been shown in another place,* so that his statements must be received with some caution. He nowhere, in his official report, speaks of any phenomena of former more extensive glaciation, or of any accumulations of the "superficial deposits," as he calls the most recent formations, as having the character of moraines. He considered that he had obtained proofs that the continent was depressed, during the Northern Drift period, to a depth of nearly 3,000 feet beneath a sea in direct connection with the Arctic Ocean, and that since then, to use the author's own words, "during its gradual emergence, the prairie region of North America has received its present form of surface by denudation, first, as effected on sea-coast lines; secondly, by the coast-lines of great inland lakes, which, it will be shown, though still existing, were previously of much greater dimensions; and, thirdly, by atmospheric agencies wearing away the soft strata, aided by streams." Dr. Hector speaks of the "glacial markings" on the rocks of Vancouver Island, to which reference will be presently made. He saw solitary boulders of great size resting on the "shingle terraces" — and by this term he evidently means the local drift accumulations — "in the woods to the south of Fraser River," at a height not more than 100 or 200 feet above the sea-level. In his final summing up of the drift phenomena of the Pacific Coast, he remarks as follows: "As I never observed drift or boulders within the Cascade Range, even in places elevated only 600 or 700 feet above the sea, but as all the superficial deposits in the great trough between that range and the Rocky Mountains clearly are formed from the re-arranged materials of the shingle terraces, along with tufas from the Cascade Range, I conclude that the average lowest altitude of the Cascade Range, which is somewhere about 4,000 feet above the sea at the present time, exceeded the depression of the continent during the glacial epoch, and presented a barrier to the causes which transported the erratics and scratched the rock-surfaces along the Pacific Coast. If the Cascade Range at that time formed a promontory enclosing a gulf open only to the south, like the Gulf of California, it would exactly fulfil these conditions."

In regard to the former glaciation of the Rocky Mountains, where crossed by the boundary line, in latitude 49°, we have the statements of Mr. G. M. Dawson, the Geologist of the British North American Boundary Commission, who speaks of the effects of glaciers as being frequently apparent along his route. The descriptions given, however, do not convey the idea that the

* See Auriferous Gravels of the Sierra Nevada of California, pp. 69, 70.

phenomena are particularly well-marked, or on any large scale. At Chief Mountain Lake, 4,213 feet above the sea, near its northern end, a "collection of rounded and hummocky hills" is thought by him to prove the former presence of large glaciers, although the hard limestone over which it must have passed showed no signs of striation. The only place where glacial striation was actually observed was in the Valley of the Kootanie Pass, where the surface of the hard green slate had markings upon it coinciding in direction with the main trough of the valley. Moraines are described as existing farther up the valley, neither the locality nor the elevation being given with any degree of precision.*

From the character of the evidence presented by Mr. Dawson, together with that furnished by Dr. Hector, it may be pretty safely concluded that the Rocky Mountains in their extension north of the parallel of 49° do not exhibit any very remarkable indications of former glaciation. This inference would be corroborated by the account furnished by Mr. Selwyn, Chief of the Canada Geological Survey, of an expedition to the head of Peace River, at a considerably higher latitude than the region visited by the Palliser Expedition. Mr. Selwyn, as previously mentioned, saw no glaciers or permanent snow in that region, neither does he make any mention of traces of former glaciation in that portion of the chain examined. At all events, there is no evidence anywhere in the Rocky Mountains, either to the north or to the south of the boundary line, of a transportation of detrital material in any general direction independent of the present topography.

Between the Rocky Mountains and the Cascade Range in British Columbia is an extensive area of country drained by the Fraser and Columbia rivers and their numerous branches, both of which streams run, for a long distance from their sources, in a northwesterly direction, then turn abruptly and pursue a parallel course in the opposite direction.† The region thus included between the two principal divisions of the Cordilleras is far from having been mapped with any approach to accuracy, but its most striking topographical features are pretty well known in a general way. It is by no means a level country; on the contrary, it is everywhere rugged and even mountainous, although the irregular ranges do not appear to attain anywhere an elevation equal to that of the dominating points of either the Cascade or the Rocky

* Report on the Geology and Resources of the Region in the Vicinity of the Forty-ninth Parallel. Montreal, 1875. p. 245.

† The Columbia River rises near the parallel of 50°, and runs northwest to a little beyond 52°, where it joins the Canoe River, coming from exactly the opposite direction and heading near 53°.

Mountains. The interesting features of the region in question are the lake-like expansions of the rivers, and the remarkable regularity and development of the terraces with which lakes and rivers are almost everywhere bordered. Some of the streams are almost unbroken lines of narrow lakes with short connecting river portions between; as, for instance, the Columbia and the Okanagan. The general direction of these lakes is either parallel to that of the enclosing ranges or at right angles to it. A glance at a map of British Columbia will show better than words the position and the peculiar orographic development of these wonderful expansions of the rivers.

The terraces of Fraser River and its affluents have been repeatedly noticed by scientific explorers and other travellers, although not as yet described with accuracy.* These terraces, or benches as they are usually called in that region, seem to be found almost everywhere on the Fraser and Columbia and their branches. They are often very numerous, there being near Lillouett, for instance, as many as fifteen or sixteen. Some observers notice the fact that for a long distance on the main Fraser there are three such benches, of exactly similar height on each side of the river, the highest of which is about 500 feet above the present level of the water.† Although it seems to be nowhere positively stated that these benches slope with the bottom of the river valleys along which they occur, there can be no doubt that such is the fact. Like all, or almost all, such terrace formations, they are the indications of a former higher stage of the water in the streams. The country has been gradually relieved of a portion of its surplus water, not by its elevation above the sea-level having been increased, as is often supposed, nor by the bursting of successive barriers along the course of the valleys, a theory even less tenable than the other; but simply because the quantity of water now passing down these valleys is far less than it formerly was. This condition is in entire coincidence with all the facts developed by geological investigation on the Pacific Coast, as has already been abundantly set forth in the volume devoted to the Auriferous Gravels.

The questions which at present concern us particularly are, whether there

* See Report of Progress of Geological Survey of Canada for 1871–72, p. 55; Milton and Cheadle, The Northwest Passage by Land; G. M. Dawson, in Quarterly Journal of the Geological Society, Vol. XXXIV. p. 111; Proceedings of the Royal Geographical Society, Vol. XV. p. 133, where a paper on these terraces, written by M. R. Begbie, will be found, together with appended remarks by Dr. Cheadle and others.

† Mr. G. M. Dawson claims to have found terraces at much greater elevations. He says "the highest perfectly distinct line was estimated to reach 1,500 feet," that is, above the level of the river. This detrital accumulation he thinks may possibly have been an old moraine "of a great glacier which has filled the valley."

are any proofs that the valleys of the region in question are filled with detrital materials of other than local origin, or whether there is anything in the character of the surface geology radically different from what has been observed in the ranges and valleys to the east and south. As far as can be made out from published documents, there is no reason whatever to suppose the previous existence of any other than small local glaciers (if any at all) in the region at the head of the Fraser and Columbia; neither is there any evidence that the drift is not of local origin. The form of the cross-sections of the valleys, as revealed in photographs and drawings taken at various times, shows clearly that there is almost invariably a steep slope of the detrital material downward from the enclosing mountain ranges towards the rivers, and this is abundant evidence that these materials came from the adjoining elevations, and that they in fact are exactly similar to the ordinary slopes of detritus, or "washes," with which we have already become familiar as occurring on such a large scale in California and the Great Basin. It is true that Mr. G. M. Dawson, in entire contradiction to all the facts, as the writer thinks, believes it possible that glaciers may once have filled these valleys.* The observations and theories of this observer will be referred to and discussed further on. He seems, however, not wholly to reject the view maintained above in regard to the real character of these terraces, for he says: "In some cases they [the terraces] may show merely stages in the descent of the rivers to their present levels through the wide-spread deposits of the Glacial period."

The statements made by the writer in the quotation given above from the California Academy's Proceedings, seem to be entirely borne out by an overwhelming weight of evidence, for the whole area embraced within the Cordilleras, with the exception of the portion which remains yet to be inquired into, namely, the ranges bordering the coast in British Columbia from Vancouver Island northward. To this region the attention of the reader may now, therefore, be called. At the time the article in question was written, or fourteen years ago, almost nothing was definitely known of the character of the coast north of Oregon. The investigations of the writer and Mr. Gabb on Vancouver Island and up the Fraser River were necessarily of the nature of hasty reconnaissances.† Mr. Ashburner, formerly of the Geological Survey

* Mr. Dawson admits, however, that the benches in question "*look like* shore-lines, caused by the accumulation and horizontal arrangement below the water-line of débris from the mountain slopes."

† The principal object of Mr. Gabb's visit to Vancouver Island was to fix the age of the coal of that region: that of the writer was to learn something of the surface geology of the northwestern portion of our territory.

of California, had also visited Queen Charlotte Islands to examine the coal deposits, supposed at one time to be of great importance. Mr. Dall had begun his valuable explorations of Alaska, which have been continued since that time, and of which the results have been published in part.* From verbal communications made to the writer by Messrs. Ashburner and Dall previous to the publication of the article in question, the writer was led to consider that the conditions previously ascertained by the Geological Survey to exist in reference to the occurrence of the Northern Drift in California, Nevada, and Oregon were very likely to prevail all along the coast and within the limits of the Cordilleras generally, far towards the Arctic Ocean. Much opposition has been made to this view; but that which, in 1866, was perhaps rather a hazardous conjecture can now be supported by an abundance of evidence. Indeed, the statement as put forth by the writer was unaccompanied by any positive assertion, except for the regions which he himself had explored. A full discussion of the relations of the glacial phenomena of thé Pacific Coast to those of the Northeastern States cannot, however, be satisfactorily entered upon until later in the present volume. What remains to be done now is, to set forth what has been observed by various explorers in regard to the glaciation of the Pacific Coast and the Coast Ranges north of Vancouver Island.

For the extreme northern portion of the region in question we have, so far as the writer knows, no other trustworthy authority than that of Mr. Dall, whose work on Alaska, published in 1870, embodies the results of several years of research in that part of the country. Mr. Dall in this volume,† after quoting that portion of the article published by the present writer in the Academy's Proceedings which relates to the absence of the Northern Drift from the Sierra Nevada and the local character of its detrital accumulations, says, "The same is eminently true, as far as we know, of Alaska." Further on he adds, "Nor in my own observations in the vicinity of Sitka and the peninsula of Aliáska have I met with any cases of this most characteristic phenomenon of general glacial action. If the glacier field once extended over the entire coast, previous to the formation of the archipelago, we may conclude that the more northern portions of the territory, north of the Alaskan Mountains, would not have been exempt from glacial action.

* See Alaska and its Resources, 8vo, Boston, 1870; and the Pacific Coast Pilot — Alaska: Appendix, Meteorology and Bibliography, 4to, Washington, 1879; both works by W. H. Dall, of the U. S. Coast Survey.

† Alaska and its Resources, pp. 461, 462.

Three years' exploration, with a strong disposition to develop the facts of the case, failed to obtain on the shores of Norton Sound, or in the Valley of the Yukon, any evidence whatever of such action. Only once were polished rocks met with, and they proved on examination to be 'slicken-sides'; while no instances of transported materials, scratches, boulders, or moraines, were anywhere met with. The rolling and moderately elevated character of the country does not favor the development of local glaciers, such as now exist on the more southern coasts of Alaska. Thomas Simpson especially remarks the absence of drift boulders on the Arctic Coast, west of Return Reef of Franklin. These most characteristic evidences of glacial action, which a child could not overlook, are quite absent in the Valley of the Yukon."

Here, then, we have trustworthy evidence of an explorer whose attention had been especially directed to this subject, to the effect that no Northern Drift could have originated in higher latitudes and made its way to the south. If there is in any portion of the Coast Ranges of British Columbia drift which has come from the north, it must have originated or started from a point south of Alaska. In other words, somewhere within the ranges in question the detrital materials must have assumed a character quite different from what they have anywhere else in the Cordilleras, and have been swept in a direction longitudinal to the crests of the mountains instead of from them toward the valleys lying between them.

The principal evidence in favor of the occurrence of material carried southward and of striated surfaces indicating a former general glaciation of the surface independent of the present topography, is supposed to have been obtained on Vancouver Island, the statements in regard to which vary considerably. All observers, the writer among the number, have noticed the glaciated rocks in the vicinity of Victoria.* There can be no doubt that the southern end of the island has been passed over by ice; but it is not so certain whether this was in the form of the glacier or the iceberg. The writer, who by no means claims to have made an exhaustive exploration of the island, saw glacial scratches on the surface near Victoria, and along the shore for some distance above. These markings, however, seemed to him to be of the character of those made by icebergs rather than by glaciers. They were especially prominent along the projecting points of rock, and every-

* Mr. Campbell says, "I found glaciated rocks on the shore, and I was happy in Victoria." My Circular Notes, Vol. I. p. 102.

where parallel with the coast. If there was a fixed mass of ice there, it must have been a glacier coming down the straits, and not one descending from the higher parts of the island. On ascending to the higher land a few miles north of Victoria, the glacial markings were found not to extend up to any great height: none were seen at an elevation greater than a hundred feet. At one point, at an elevation of 150 feet above the sea, an angular fragment of granite eight feet long and high, and about six broad, was observed lying upon a surface of metamorphic rock, which was not in the slightest degree smoothed or polished. The impression made upon the writer by an examination, necessarily hasty, of the southern end of Vancouver Island was, that all the phenomena presented in that vicinity could be best accounted for by the supposition that large icebergs had passed down the Straits at a time when the glaciers coming down the coast farther north were considerably larger than they now are, and that these bergs had dropped occasional boulders on the surface, and had here and there produced those striations which are abundantly vouched for by Arctic explorers as being often made at the present day by floating ice. This theory presupposes a slight elevation of the land in that region since the time of the greatest extension of the glaciers, and such a rise is quite in harmony with facts observed at many points on the coast farther south. Mr. Gabb also noticed the glaciation near Victoria, but his notes make no reference to any such phenomena in the vicinity of Nanaimo. Mr. H. Bauerman* also speaks of the scratched and grooved rocks in the vicinity of Esquimalt and Victoria, but does not mention their occurrence anywhere else on the island. Mr. J. F. Campbell says: "As soon as I spied the rocks at Victoria, I recognized the familiar glaciated form. The direction of movement was parallel to the axis of Puget Sound, at right angles to the strait which opens into it from the Pacific Ocean. It follows that all this water drift, with rare glacial boulders in it, rests upon glaciated rocks. Because of shells found in the drift, the glacial period here was marine." Mr. Selwyn also noticed the appearances at Victoria,† and says: "Of the existence of ice-grooves on the shore of Vancouver Island there can be no question. Inland neither Mr. Richardson nor I observed any."

There is considerable evidence, on the other hand, that Vancouver Island has been the theatre of a much more extensive glaciation than would be in-

* In an article entitled, "On the Geology of the Southeastern Part of Vancouver Island," Quarterly Journal of the Geological Society, Vol. XVI. p. 198.

† Geological Survey of Canada. Report of Progress for 1871–72, p. 53.

ferred from the authorities cited above. Two observers have been especially active in this direction, and have published their views on the subject at considerable length; these are Mr. G. M. Dawson, to whom reference has been previously made, and Dr. R. Brown, who devoted a part of the years 1864 and 1866 to an official scientific examination of the island.* The titles of the papers published by the last-named explorer, in which the subject of Northern Drift is discussed, are given below; but the last one published, namely, the one in the American Journal of Science, will be chiefly used in this connection, as containing the latest and fullest exposition of his views. In this paper Dr. Brown remarks as follows: "So far from the Northern Drift being absent from Vancouver Island and British Columbia, it is present in as marked a manner as ever I saw it in countries celebrated for the presence of such remains." This is much stronger language than had been previously used by the same observer in a communication published some years earlier, and immediately after the completion of his work on the island. In that statement he speaks only once of glacial and drift phenomena, and that in a chapter of his communication which is credited to other persons, it being stated at its beginning that it was compiled from accounts furnished by four of his *employés*, who appear not to have been scientific observers, one of them at least being an Indian guide and hunter.† The paragraph in question reads as follows, in an English translation: "These hills appear to be made up of masses of Plutonic rock, covered with a thin layer of humus, here and there strewn with erratic blocks, which form a part of the Great Northern Drift formation, to be found all over Vancouver Island. Indeed, some of the principal edifices of Victoria are built of a gray syenite which is not to be found *in situ* nearer than Alaska." It is hardly necessary to call attention to the extraordinary character of this last statement, put forth by one who had never made any detailed examination of the country to the north.‡ A similar disregard to scientific accuracy of statement will be

* See Mr. Dawson's paper "On the Superficial Geology of British Columbia," Quarterly Journal of the Geological Society, Vol. XXXIV. p. 89.

Dr. Brown's principal papers are: Das Innere der Vancouver Insel, in Petermann's Mittheilungen for 1869, p. 1; On the Geographical Distribution and Physical Characteristics of the Coal-Fields of the North Pacific Coast, in Transactions of the Edinburgh Geological Society, Vol. I. p. 305; On the Supposed Absence of the Northern Drift from the Pacific Slope of the Rocky Mountains, in the American Journal of Science, Second Series, Vol. L. p. 318.

† See Petermann's Mittheilungen, 1869, p. 4.

‡ All that Dr. Brown had seen of the region to the north of Vancouver Island seems to have been comprised in a hasty visit to the Queen Charlotte Islands.

found pervading the whole article in question. For instance, it is remarkable that no clew is given to the heights at which the erratic blocks actually observed were seen; neither is there any precise statement of locality in Dr. Brown's communications, excepting the three-times repeated information in regard to the granite of which some buildings at Victoria have been constructed. There is nothing in either of the three papers whose titles have been given which is inconsistent with the idea previously advanced by the present writer, that icebergs have passed over portions of the island and dropped occasional boulders on the surface, at a time when the level of the land was not as high as at the present time by one or two hundred feet. This indeed might seem to be the idea of Dr. Brown himself, who thus expresses himself in speaking of the Victoria erratics: "I am not aware that any rock of a similar description is found *in situ* anywhere in Vancouver Island [this is rather different from the former positive assertion that no such rock could be found in place south of Alaska]; it appears to have drifted in icebergs from the north." Dr. Brown quotes Mr. Bauerman as authority for the occurrence of "true glacial or boulder clay in various portions of Vancouver Island"; but the truth is, that this geologist, as already mentioned, describes nothing of the kind except at Victoria and its immediate vicinity. And, in addition to this, it is from Mr. Bauerman himself that we have the important statement of the finding of marine shells in the so-called glacial drift,—a sufficient indication, one would suppose, that here could be no question of glaciers proper, but rather of iceberg agencies. Dr. Brown was evidently at the time he visited Vancouver Island an entirely unpractised observer. There is a vagueness about all his geological data, which makes it quite impossible to use them in arriving at definite conclusions in regard to the former glaciation of the northwest coast.

Mr. G. M. Dawson, in his already quoted paper, gives a much more definite account of his observations on the glaciation of Vancouver Island than does Dr. Brown of those made by himself and party. Mr. Dawson, however, like almost all other geologists who have visited the island, confines his remarks principally to the neighborhood of Victoria. Indeed, he gives no positive statements of any kind in this connection except for localities in the immediate vicinity of that city. The highest point at which he professes to find glacial markings is on the summit of Mount Douglas, or Cedar Hill, a rocky eminence 696 feet high, but even here he himself admits that there is some uncertainty, for he remarks that "the direction of the glaciation" is due south, *as nearly as can be ascertained.* There is no difficulty in ascertaining the direction of striæ which are well defined, as every geologist knows.

Mr. Dawson confirmed the investigations of Mr. Bauerman to a certain extent, by finding marine shells in several localities in the so-called glacial drift. It is a little curious that the points where these discoveries were made are not stated; but from the context they would appear to be in the immediate vicinity of Victoria. His theoretical results are given in the following words: "There appears to be no escape from the conclusion that a glacier swept over the whole southeastern peninsula of Vancouver Island at some time during the Glacial period; and on consideration of the physical features of the country it becomes apparent that the entire Strait of Georgia between the island and the mainland must have been filled with a great glacier, with a width in some places of over fifty miles, and a thickness near Victoria of *at least* considerably over 600 feet." This last statement of thickness seems to depend entirely on the single observation on Mount Douglas, previously referred to, confessedly of an unsatisfactory character, and in conflict with the observations of the present writer, as well as those of Messrs. Selwyn and Richardson of the Canada Survey. Mr. Dawson himself appears to be struck by some of the difficulties in the way of the adoption of his own theory, for he adds immediately after the lines above quoted: "With all this, however, there has been very little general wearing-down of the rock-surface of the country; all its main features, *and, in many cases, even the most minute* [the italics are the present writer's modification of the original] *are clearly of preglacial origin.* The valleys generally follow bands of limestone and softer schistose and shaly beds, and run as often transverse to, as parallel with, the direction of glaciation; and besides the general forms of the smaller hills, little rocky knolls and projecting points of rock, while worn and rounded to the north, preserve rough unpolished southern faces. This feature is more marked than I have elsewhere observed, and would seem to indicate, even allowing that glaciers do not very rapidly abrade solid rocks, that the ice did not long rasp over this portion of the country, and possibly that it never extended much beyond this point."

It is surprising that Mr. Dawson did not see how much better the theory of iceberg agencies would adapt itself to an explanation of the above described phenomena, than the one which he adopts, namely, that of a great glacier which has no apparent head, and which comes to a sudden stoppage when 600 feet thick, and whose manifestations are almost or quite exclusively limited to its very termination. Here we ought, if we adopt the glacier theory, to expect to find large moraines, of which no trace has ever been observed by any one, for the term "glacial drift" means nothing, unless its real character is somewhere distinctly defined. Glacial drift may be dropped a thousand miles away from any glacier, and scratched and polished rocks can be, and are now, produced in abundance, not only by icebergs, but by shore-ice, on the borders of the sea, as well as on those of great lakes, as will be noticed further on.* The finding of marine fossils at various localities in the midst of the glaciated region is, as the writer conceives, fatal to the glacier theory. Their presence is thus accounted for by Mr. Dawson: "The general appearance of the deposits of this part of Vancouver Island, resting, as they do, on planed and polished rocks perfect in every detail and necessitating glacier action for their explanation, and yet consisting of water-bedded and often current-driven materials mingled in places with sea-shells, leads to the belief that they were formed along the retreating foot of a glacier which had extended some distance beyond the margin of the land. The withdrawal of the ice may have been caused or accompanied by subsidence; and some species of shells must have followed its front pretty closely in its retreat. The somewhat irregularly terraced form of the deposit is probably due to action during emergence; and the general tendency of many facts is to show that a slight sinking of the coast is at present in progress or has lately occurred."

Before entering into any further discussion of the glacial phenomena manifested on Vancouver Island, and the true relations to the Northern Drift epoch, something must be said in reference to the character of the coast farther north between that island and Alaska, an extremely interesting region on account of the deep indentations of the shore-line and the grand mountain ranges which press upon it. This region has not, as yet, been much explored, and the little we know of it, beyond the mere position of the coast-line, is due to the reconnaissances of the Canada Geological Survey. It is quite clear, however, that the range of lofty mountains bordering the coast has been occupied, in its higher portions at least, by extensive glaciers; and that these have found their way down the cañons to the very sea-level in places is also highly probable. This is in entire harmony with all that we have learned from the preceding pages in regard to the phenomena of former glaciation in the high ranges adjacent to the Pacific. The

* See also page 11 of this volume.

ranges north of Vancouver Island were so situated, with reference to the prevailing winds, as to condense by far the larger portion of the moisture swept inland from over the ocean surface,—a condition of things perfectly in accordance with what is now taking place along the Pacific Coast farther south, as an inspection of the Smithsonian rain-charts well illustrates. How extensive the glaciers were in these comparatively high latitudes, on a lofty range rising almost directly from the sea to a height of six or eight thousand feet, can only be told by actual observation; that they were of such gigantic dimensions as to unite in one main stream of ice filling the Straits of Georgia, moving southward and impinging against the base of the Olympian Range, as maintained by Mr. Dawson, does not seem to have been proved, as has been set forth in the preceding pages.

The investigations of Mr. James Richardson, of the Canada Geological Survey, who had an opportunity of examining many of the inlets north of Vancouver Island, seem to have been carefully and conscientiously made. His observations all go to prove the former existence of large glaciers in the range along the portions of the coast seen by him on a trip from Douglas Channel to Wrangel in Alaska. His remarks on this subject are instructive, although brief, and may be here quoted in full.* "Throughout the whole of the inlet and channels which were examined, wherever the surface of the rock is exposed, the ice-grooving and scratching is very conspicuous, from mere scratches to channels often several feet in width, and from a few inches to as much as two and three feet deep. Often they can be distinctly seen with the naked eye from the surface of the water to upwards of 3,000 feet above it on the sides of the mountains. They run in more or less parallel lines, and are not always horizontal, but deviate slightly up or down. Sometimes the rocky surface resembles that of a field covered with narrow ridges. Where two valleys meet, the upward deviation is always well marked on the side of the smaller valley. A good example of this occurs at the junction of the Kamino Valley with that of Gardner Channel, where on the west side the hard gneissose rocks are scooped out in wide deep grooves, occasionally undercut on the upper side, and rising from the level of the water at angles of from eight to fifteen degrees. It would be useless to enter into any great detail as to the direction of the grooves. *Generally, it conforms with that of the valleys*,† and the movement of the ice has

* Geological Survey of Canada. Report of Progress for 1874-75, p. 81.

† Italicized by the present writer.

been from north, northwest, northeast, and east to the opposite point, modified by the sinuosities of the valleys through which it passed." *

Mr. Dawson continued his observations from Vancouver Island northward through the Straits of Georgia for some distance along the coast; but he states that his opportunities for examining the remarkable fiords by which the coast of the main-land is indented were but limited. The only one ascended to its head was Bute Inlet, the mouth of which is about opposite the centre of Vancouver Island, in latitude 50° 30′. Of this he speaks as follows: "This chasm, forty miles in length, and running into the centre of the coast range, is surrounded by mountains which, in some places, rise from its borders in cliffs and rocky slopes to a height of from 6,000 to 8,000 feet. It must have been one of the many tributaries of the great glacier of the Strait of Georgia, and accordingly shows evidence of powerful ice-action. The islands about its mouth are *roches moutonnées*, polished and ground wherever the original surface has been preserved. In Sutil Passage, near its entrance, grooving appears to run about S. 30° W. A precipitous mountain on Valdez Island, opposite Stuart Island, and directly blocking the mouth of the inlet, though 3,013 feet high, has been smoothed to its summit on the north side [the Inlet has an almost exact north and south course] while rough towards the south. The mountain-side, above Arran Passage, shows smooth and glistening surfaces, at least 2,000 feet above its face; and in general all the mountains surrounding the fiord present the appearance of having been heavily glaciated, with the exception of from 1,000 to 2,000 feet of the highest peaks. The high summits are rugged and pointed, and may either never have been covered by glacier-ice, or owe their different appearance to more prolonged weathering since its disappearance. In some places parallel flutings high up on the mountain-sides evidence the action of the glacier; while in others it is only attested by the general form of the slopes, or detected under certain effects of light and shade. At the mouth of the Howathco River, discharging into the head of Bute Inlet, striation shows a direction of movement S. 22° E.; but in every case the motion appears to have been directly down the valley, and to have conformed to its changes in course."

The above citations seem to include all of importance that can at present be stated in reference to the former glaciation of the Coast Mountains, oppo-

* This quotation from Mr. Richardson's report has been given by Mr. Dawson in his article on the Superficial Geology of British Columbia, previously referred to; but all of it which relates to the conforming of the direction of the ice-grooves with that of the valleys, and the deflection upward from the level of the water, which seems to indicate iceberg or shore-ice action, has been omitted by him.

site Vancouver Island, on the main-land, and farther north towards Alaska. There can be but little difference of opinion in regard to the general character of the former glaciation of the high range in question. The position and direction of movement of the ice-masses was evidently governed by the topography of the country, which at the time of the former greater extension of the glaciers was in harmony with what it now is. There is a strong body of evidence, as the writer thinks, to the effect that the ice-markings near Victoria were the work of icebergs, and not of a gigantic glacier filling the Straits of Georgia, as advocated by Mr. Dawson. So immense a development of land-ice as Mr. Dawson's glacier would require seems not to be in harmony with what has been observed in regions farther south, or in the same latitude to the east. The very uniform character of the manifestations of the former presence of ice, over a length of more than a thousand miles, in the ranges extending along the coast from Oregon to Southern California, leads us to infer that so enormous and sudden an expansion of glacier-covered surface as that demanded by an ice-mass filling the Straits of Georgia is something not to be accepted, unless thoroughly demonstrated by a series of carefully conducted observations. Be this as it may, however, it must be manifest to all that we have in this former extension of the glaciers, even adopting Mr. Dawson's views, nothing which can be properly classed with the Northern Drift, as will be more fully explained further on in this volume.

Neither can the phenomena described by Mr. Dawson as occurring in the interior of British Columbia, east of the Coast Ranges, be regarded as indicative of anything more than local glaciation on a large scale, even if his observations be accepted as entirely trustworthy. But as it appears that some explorers and geologists see, with the greatest facility, glacial markings of all kinds, and in perfection, where others of at least equal experience are unable to discover them at all, it may be deemed advisable to wait until further evidence is obtained before concluding that the Fraser River Valley was the scene of such an exceptionally large development of ice during the Glacial epoch. The relations of the admitted conditions of glaciation in the Far Northwest to those of the northeastern part of North America will, however, be best discussed at a later period in this work. That Mr. Dawson himself perceives the theoretical difficulties which present themselves in connection with the facts which he professes to have observed, and that there is some uncertainty in regard to these facts themselves, will, as the writer conceives, be apparent from the following quotation from the summary of his remarks on the glacial geology of the region in question.*

"In attempting to cover with any general theory the traces of the last great period of cold, generally known as the glacial period, in a district the physical features of which are so well marked and so varied as those of that under discussion, much difficulty is felt, owing to the great number of possible combinations of circumstance. The earliest recognized traces of the period of cold are doubtless the markings on the surface of the plateau, or high lands, in connection with it, which indicate the southward passage of massive ice. These, by the observations above detailed, have now been found in different parts of the interior plateau, for a distance of over 300 miles, and traced up, on Iron Mountain, to a height of 5,280 feet. Erratics and drift material, with evidence of water action, occur to a like elevation. *When compared with the ice-markings found in the lower valleys, and to those of the south-eastern extremity of Vancouver Island, known to be due to glaciers, those of the higher parts of the interior plateau are less definite.*† The rocks are frequently well polished, with striæ faintly marked, and varying several degrees in direction. *Heavy grooving or fluting like that frequently observed where true glaciers have been at work, is seldom or never seen,* the nearest approach to it being on the summit of Tsa-whuz and Iron Mountains."

Dr. Dawson infers from all the facts observed by himself that it is "not improbable" that a great confluent glacier did, at an early stage of glacial time, cover the interior of the Province of British Columbia. This sheet, he says, need not have been much more than 2,000 feet in thickness, and its greatest efflux was doubtless by the valley and comparatively low country of the Okonagan. If, however, this enormous glacier did discharge itself chiefly through the valley of that river, the evidences of such outflow would, beyond doubt, be of the most striking character. Enormous moraines would be accumulated all through the region, and the surface far and wide would be covered by erratics, and the piles of débris formed by the action of the water resulting from the melting of the ice, on the detrital material previously brought down from the region to the north. An examination of all that has been published by trustworthy observers in regard to the surface geology of that region indicates that nothing of this kind is to be found there. As admitted by Mr. Dawson, however, a considerable portion of this great ice sheet

* Geological Survey of Canada. Report of Progress for 1877 – 78, p. 150.

† The author has taken the liberty of italicizing one or two passages in the quotation cited above.

must have found its way out by the Valley of the Fraser. Here, again, the evidences of such passage of a great glacier 300 miles long are singularly defective. The few isolated boulders observed resting on the surface of the local detritus, by Dr. Hector and others, are but a poor representation of the former passage of a mass of ice larger than any now existing in the world, unless in Greenland or at the South Pole. That these and other similar difficulties did not fail to impress themselves on the mind of Mr. Dawson, and that he was inclined to look with suspicion on his own "highly probable" theory, is shown by the following extract from his report on the region in question, which follows immediately after the suggestion of the great confluent glacier, which he supposed to have covered so large a part of the interior of British Columbia. He says: "It is well to remember, however, that the hypothesis of an Arctic current bearing heavy polar ice through the Peace River gaps at the north, and thence southward down the region of the plateau, *would serve almost equally well to account for its glaciation.*" And he adds: "Any theory of the cause of these traces of the earlier glaciation shall at present be held tentatively, and subject to the result of further exploration."

In the preceding pages will be found, it is believed, all that it is necessary to set forth in regard to the former glaciation of the western side of the North American continent. With the facts which have been given, the reader will be prepared to enter into the discussion of the probable relation of the phenomena of past glaciation, as manifested on the Pacific Coast and in the Rocky Mountains, to similar occurrences in other parts of the world. Before advancing another step in the present inquiry, however, it will be desirable to add to what has already been said about glacial phenomena proper something in regard to one or two points of surface geology more or less directly connected with the former occurrence of ice in the regions which have been passed over in review in the preceding pages. And it will also be proper to inquire whether there are any points in regard to the distribution of the superficial detrital material, in the non-glaciated portion of region in question, which require special elucidation, as preparatory to the discussion which it is proposed to enter upon in the succeeding chapters.

One of the first questions suggesting itself to the student of dynamical geology, in connection with the phenomena of past glaciation which have been described in the preceding pages, is this: Are there any marked, characteristic features in the topography of the glaciated regions which distinguish them from the non-glaciated? In the use of the phrase "characteristic features," it is not intended to include such phenomena as have been fully indicated above as being the legitimate work of the glacier, but to suggest the possibility of other more obscure and uncertain results of ice-work which may not reveal themselves at once to the observer, but which, on the other hand, may be deciphered by a careful study of the topographical features of the regions in which ice has been shown to have done geological work in former times. Among such results might be the occurrence of lakes, to which reference has already been made, or peculiar forms of the cross-sections of the valleys, or the terraced arrangement of the detrital materials; and in reference to each of these topics some remarks will here be made, which may be taken as supplementary to anything which may have been said on the same subjects in previous pages.

In regard to the formation of certain lakes partly or wholly through the agency of ice a few words may here be introduced. And first with reference to what has more especially come under the writer's own observation, in California and the Great Basin. All the important lakes of California are strictly of orographic origin; that is to say, the water which fills them occupies portions of depressions which have been produced, not by eroding agencies of any kind, but by the same crust movements which have given rise to the mountains and valleys. We find lakes of this kind somewhat abundant in California, and in all stages of progress toward entire desiccation, as will be set forth in the next chapter. Most of these lakes belong to the Great Basin system; they are to the east of the main divide of the Sierra Nevada, or entirely to the south of that chain. These will be noticed more fully in connection with the phenomena of their gradual diminution, as indicating one of the most general and important climatic changes of later geological times.

The Coast Ranges of California enclose within their limits but very few lakes, either large or small. South of San Francisco Bay, indeed, there is hardly a single body of water worthy of being called a lake. This is naturally to be expected, since the rocks are, almost everywhere, very permeable, the precipitation moderate, or even small in the southern portion of the State, and the evaporation large. Clear Lake offers a striking exception, and is the only body of water of any importance within the Coast Range system. It is clearly of orographic origin, and it marks the termination of the volcanic formations on the north.

The Great Valley of California was once a lake of magnificent dimensions, but it now retains its lacustrine character only at its extreme southern end. The orographic depression between the Sierra Nevada and the Coast Ranges must once have been very deep, as well as of great length, since it has been the recipient of all the detrital material swept down from both sides, although in vastly larger quantity from the eastern, during a long period of time. How deep these accumulations are is unknown; a bore of a thousand feet in depth at Stockton, about midway in the valley longitudinally, did not reach its bottom.* A large part of the southern end of the San Joaquin Valley is liable to be converted into a lake after a succession of unusually rainy seasons. It is a swampy region overgrown with tules, having one large but very shallow permanent body of water near its centre, and about midway between the extreme southern end of the valley and the point where the San Joaquin River debouches from the Sierra. This lake, called Tulare, from the growth of tules (*Scirpus palustris*) which surrounds it, has an area at ordinary times of 600 or 700 square miles, and a depth of only forty feet; but its dimensions vary considerably from year to year. The reason why water stands in the southern portion of the San Joaquin Valley is, that the rivers coming down the slope of the Sierra farther north have filled up the depression more rapidly than those to the south, and thus formed a kind of dam or barrier to the escape of the water, or to a perfect drainage of the southern part of the valley. This larger supply of detrital material from the more northern streams is due in part to the increased precipitation as we go north on the slope of the Sierra, in part to the greater development of the belt of schistose and more easily disintegrated rocks, and also, to considerable extent, no doubt, to the vastly increased supply of volcanic material north of the San Joaquin River, which in places forms deposits of great thickness along the foot-hills, and much of which was of a nature to be most easily and rapidly eroded away.

The western slope of the Sierra Nevada is almost entirely destitute of any lakes, except those very minute ones high up in the range, to be presently described. Bodies of water of considerable size once existed there, although not in abundance; but they have nearly all disappeared, having become converted into sedge-grass meadows, or "flats," as they are usually called. The slope of the range and its orographic simplicity are manifestly unfavorable to the development of permanent lakes; the depressions which

* For some details as to the form of the cross-section of the Great Valley, see Auriferous Gravels, p. 2.

originally existed in it, as shown by the form and position of the Tertiary gravel deposits,* have long since been filled up. Lake Tahoe, however, as already mentioned,† is a fine, and for California an exceptional, example of an orographic lake of pure water and large dimensions. Situated in a depression between two elevated ranges, on the very summit of the Sierra, it is chiefly supplied by melting snow, and is kept fresh by the abundance of this supply while its overflow is carried to a lower level, within the Great Basin, there to disappear by evaporation in Pyramid and Winnemucca lakes. The great depth which the depression occupied in part by Lake Tahoe must originally have had, becomes evident when it is considered that, in spite of the detrital material to it from the adjacent lofty ranges, it has still a depth of considerably over a thousand feet.

No one of the lakes mentioned above could for a moment be supposed to be of glacial origin; but there are others, mostly of minute size ‡ and very numerous, in the formation of some of which ice has undoubtedly had a share. The greater part of the more important of these are so-called "moraine-lakes," the origin of which is exceedingly simple. A stream of water is dammed back by an accumulation of glacial débris, and a lake, of greater or smaller size, is the result. Such lakes are usually shallow and not permanent. The barrier may be broken away at any time; and with the universal shrinking of the glaciers which has taken place in later geological times, the majority of the lakes thus formed have also disappeared.

There are other lakes which are usually even smaller than those of moraine origin, and which occur high up in the mountains at the very heads of the streamlets, and whose basins have unquestionably been formerly occupied by glaciers. The basins of such lakes are always shallow, usually very much so, and of solid rock, with little or no débris about them. As these small bodies of water are quite at the heads of the streams, and at very high altitudes, they must occupy positions where, during the glacial epoch, snow or *névé* existed. They are, in most instances, higher than the ice could have reached, and therefore higher than the region where the glacier did most of its work. Their extreme shallowness, however, renders the question how they are kept filled with water one of more importance than that of their

* See Auriferous Gravels, *passim*.

† See *ante*, p. 57.

‡ These lakes are by far too small to be shown on ordinary maps: more than fifty of them are indicated on the Geological Survey "Map of a Portion of the Sierra Nevada, adjacent to the Yosemite Valley," which is on a scale of two miles to an inch.

original formation. If they were empty, their existence would hardly be observed; they might even escape notice altogether. The principal reason why the water stands in these shallow basins is, that the rock, which is exclusively granite, is impermeable: it holds up the water almost as well as metal would do it. Again, the supply of water to keep them filled is readily forthcoming from the melting of the snow, which usually lies almost or quite through the year at the base of the cliffs by which these little pools of water are surrounded. That there should have been inequalities existing in the surface of the granite at the time the Glacial epoch commenced, can certainly not be a matter of surprise; that the glacier, with the aid of the water produced by its melting, kept these depressions free from débris, or even, in places, deepened them somewhat, is also a condition of things easily understood. The more difficult point seems to be, to find an answer to the question why these hollows have not become filled up with the débris from the adjacent slopes since the disappearance of the glaciers. This leads us to the discussion of another interesting point which presses itself upon the attention of the observer of the phenomena of past glaciation in the Sierra Nevada.

The point is this: the more one studies the localities formerly covered with ice in the region in question, the more one is impressed by the fact that but a short period has elapsed since this ice disappeared. The Glacial epoch — for California, at least — is only just over. This is shown in many ways, by none, however, more satisfactorily than by the astonishing perfection with which the glacial polish has been preserved over large areas formerly covered by ice. That the surface should retain the striations and polish for a long time, and in great perfection, where the rock was, immediately after their production, covered deeply with débris and soil, is not so remarkable. There are many localities in New England and in the vicinity of the Great Lakes where the striæ are almost as fresh looking as if just made; but in all such cases the rock surface has only been recently stripped of its detrital covering by the hand of man or otherwise. All through the Sierra, on the other hand, where the granite is entirely bare of overlying débris, and appears to have remained so ever since the ice left it, the polish is apparently as perfect as it was when first made. The only theory by which these facts can be explained is this, that but a short period of time has elapsed since the work was done. It might perhaps be argued that the surface had remained covered with débris until a recent period, and that this has only lately been removed. This, however, is not a tenable supposition in view of the fact that the moraines remain in such a perfect state of preservation. In many places they look as fresh and unimpaired in the completeness of the details of their forms as do those of the present Alpine glaciers. These remarks apply especially to the glaciated regions of the Sierra Nevada; but the freshness of the glacial markings in the Rocky Mountains is not much less striking than on the western edge of the Cordilleras. The writer did not see any surfaces of rock in the mountains about South Park or at the head of the Arkansas River which retained their polish as perfectly as those at the head of the Tuolumne and elsewhere in the Sierra; but the moraines descending the eastern flanks of the Sawatch Range seem entirely unimpaired, perhaps quite as much so as those previously described as occurring in the vicinity of Mono Lake. The contrast is very striking between the freshness of the indications of the former presence of ice in the Cordilleras, and of those which display themselves in Northeastern North America; to the character of these latter attention will be more specially directed further on in the present volume. It may be added here, however, that there is strong reason to believe, as the writer has become convinced by repeated examinations of both regions, that the period of the former more extended glaciation of the Alps dates back further than that of the similar geological events in the Cordilleras.

This simplicity of the phenomena of former glaciation in the Cordilleras leads us also to infer that the time occupied by the Glacial epoch in that portion of the continent must have been much shorter than that during which the complicated series of events occurred which are referred to the period of the Northern Drift in the Northeastern States and the region of the Great Lakes. There are important general conclusions connected with this aspect of the glacial question; but their consideration may properly be put off until a more advanced stage of the present discussion has been reached.

Some words may be added in this connection in reference to a subject discussed at some length in the Auriferous Gravels, namely, the forms of the valleys or cañons in the Cordilleras, the especial question here to be considered being whether the former presence of ice reveals itself in any easily recognized manner in the figure of the cross-section of the valleys through which it has passed. Observers frequently speak of the characteristic U-shape of glacial valleys, as contrasted with the V-form of cañons resulting from aqueous erosion. This is an error partly of misapprehension and partly of exaggeration.* The fact is that the forms of valleys depend on a much more complicated series of events than would be indicated by the use of the simple phrases "aqueous" or "glacial." There is the original form to be considered, in the first place. Something determines the passage of ice or water along a certain line, or in a certain direction. This something is of an orographic nature. Whoever has studied the structure of the earth's crust as revealed in the many sections afforded by great mining operations, especially those made in the Carboniferous rocks on so grand a scale in Europe, must have been impressed with the manner in which portions of the earth's crust have been thrust up or down along vertical or nearly vertical planes. Here is nothing of theory: the facts are of too much importance, from an economical point of view, to be ignored. To assume, as some geologists do, that great chains of mountains, made up as many are in large part of thoroughly squeezed, folded, and overturned rocks, had originally perfectly uniform surfaces, which have since been eroded by water or carved by ice into their present forms, is to occupy a position emphatically at variance with the great body of facts developed by geological investigations. It is only under peculiar and exceptional circumstances that water has done most of the work, as for instance in the case of the cañons of the Colorado River and its side valleys. As a general rule it is safe to assume that where U–shaped valleys exist, the perpendicular walls have an orographic origin, and that those of V–form have had that shape given to them by the débris piles which have accumulated against their sides. The farther we descend the mountain slope, the less the grade, and consequently the less the carrying power of the stream: hence, the valley which is U–shaped in the upper part of its course acquires more and more of a V–form as it approaches the plain at the base of the range in which it heads.

But glaciers have been and are now limited in their occurrence chiefly to the higher portions of the mountains, hence their association in the mind with the U–form of the valley. And this leads superficial observers to conclude that the U–form is the work of the ice itself; while the truth is, that the material from which the glacier has been formed has simply been gathered together in a pre-existing depression, all observations showing that great *mers de glace* can only accumulate where the topographical conditions are

* Mr. J. F. Campbell expresses the same idea, but in a form much more limited and nearer the truth. He says: "Every agent that wears rock leaves a different mark. A glaciated valley has a rounded section ◡ ; a stream cuts a V or a Y."

favorable. That the glacier, having been formed, carries away the detrital material which falls upon and delivers it at a distance from the place of its origin, thus keeping the depression from becoming partly or entirely filled with débris, is a phenomenon which is of too simple a character to require comment. However great the eroding power of the glacier may be after the snow has become fully transformed into ice, there can be no question that it must be very small as long as the material of which it is formed remains snow or *névé*. Hence the utter inadequacy of glaciers to carve out for themselves the steeply walled *cirques* or amphitheatres in which they head, and which in the Sierra Nevada often have almost exactly the form of a kettle, with the rim broken away on one side.

The occurrence of terraces as indications of climatic change will come up for discussion in the next chapter, such forms of detrital accumulations being the especial result of diminution in the amount of water passing down the streams, or standing in the lakes, along whose banks they are found. Terraces are not unfrequently regarded as being in some way connected with former glaciation. It is true that where, owing to change of climate, glaciers have disappeared, there is likely also to have been a diminution of water in all the adjacent region; but moraines are the results of the work of the advancing ice, while terraces are evidences of the retreating of the water. These two forms of detrital accumulations have, however, a certain resemblance to each other, which has often led unpractised observers into mistakes.

Having thus in the preceding pages given a somewhat detailed description of the character and extent of the manifestations of the former presence of glaciers in the Cordilleras, the logical method of pursuing the subject would seem to be to pass in review other portions of the earth's surface, in geographical order, and to furnish a similar statement for all those regions which exhibit similar phenomena. It is evident, however, that such an undertaking would require far more space than could be allowed in a volume like the present. Besides, the facts are so well known and so easily accessible in a variety of works, both general and special, that it is not necessary to go over the ground again. All that needs to be done is to refer to and enlarge upon such details of past and present glaciation, in certain regions, as may have a special bearing on important points, and this will chiefly be done as these points come up for discussion. A few very important districts will be described with some fulness of detail; while for most of the regions brought under review the author will be contented with giving references to the sources from which full information may be obtained. Not, however, that it is intended here to convey the impression that all has been ascertained that is desirable in regard to the phenomena of the Glacial epoch. On the contrary, there is much yet to be learned, and there are many gaps in our knowledge which can only be filled by detailed and careful observations. This can be done better than is at present possible after some definitely established theory of the whole series of geological facts, of which former glaciation is one, has become generally accepted. At present, as is evident from an examination of the great mass of published materials, observers see, in many instances, more of what they are inclined, from previously conceived theoretical notions, to expect, and less of what really does exist.

The facts which have come under the writer's own observation in North America, and especially on the western side of the Continent, during many years of continued investigation, forming, as it were, the basis of the present discussion, have properly been set forth with considerable detail. This has been the more proper course, because it has not elsewhere been attempted to be done; nor could it have been, except by some one who had with his own eyes seen a large portion of the whole region; for the published statements of some observers are so at variance with the truth, that only utter confusion could result from an indiscriminate use of all that has found its way into print on the subject of glaciers and ice-work as manifested in the Far West.

Leaving, then, the glaciated regions of Northeastern America and of Europe to be touched upon with more or less detail in a future chapter of this work, we may now proceed to the consideration of certain phenomena of the greatest possible interest as indicative of recent climatic change, and which are manifested not only far and wide over the whole earth, but on an especially large scale, and with the greatest distinctness, in the region to which our attention has been particularly directed in the preceding pages. We refer to the diminution in the quantity of water running and standing on the surface of the country; to the drying-up which has been going on over a large part of the earth during the later geological times, a phenomenon so wide-spread and important in its manifestations as to demand a much more careful study than it has hitherto received.

CHAPTER II.

THE DESICCATION OF LATER GEOLOGICAL TIMES.

SECTION I. — *Introductory.*

CLIMATIC changes manifest themselves upon the earth's surface in a variety of ways. The one essential cause underlying all that complex of conditions to which the all-embracing term "climate" is applied is, of course, the solar heat. But the manifestations of the effects of this fundamental agency are powerfully influenced by many different causes, some of which are liable to be profoundly modified by variations of geological conditions. This subject will come up for more careful consideration at a later period in this volume; at present all that it is necessary to do is, to call attention to the fact that a diminution of the water flowing or resting motionless upon the surface of the earth — of the volume of rivers and of the area of lakes, in short — is a phenomenon which must be admitted by all to be indicative of a climatic change, the importance of which corresponds in a measure to the amount of such diminution. That such a change is now going on, and that it has been for a very considerable length of time, we shall now proceed to set forth, leaving the causes and consequences of this desiccation to be discussed in another chapter. It will become evident, on examination, that while the evidences of climatic change presented by the phenomena of extinct glaciation are extremely interesting, those of the drying-up are even more important, at least from a climatological point of view, for they can be traced over a much larger area of the earth's surface, and have been continued during a longer period, than the glacial phenomena in question. This desiccation is, moreover, especially interesting in that it is an occurrence which is not only taking place at the present day, but one which is making itself felt in many ways as affecting the movements, the prosperity, and even the life itself, of large masses of mankind.

It is indeed remarkable that so little attention has been paid to the facts which will be brought forward in the following pages. Many of them have been reported singly, but apparently without much weight being attached to them, and certainly without any very definite idea of their bearing as forming a part of a connected series of events. The almost or quite universal tendency has been, and still is, to consider climate as something on the whole quite fixed, and in its very nature invariable, or else to invoke the agency of causes of a periodical nature, involving cycles of events, but not any permanent change. That both these theoretical aspects of climatic persistency are quite contrary to the facts developed by geological investigation will be made apparent, as the writer believes, in the following pages. But without further introductory remarks, the essentially important facts will now be laid before the reader.

Section II. — *The Drying-up of the Lakes of the Western Side of the North American Continent.*

It is not difficult to understand how it is that the decrease in dimensions of a body of water like a lake is a phenomenon more striking in character and more easily recognized than the gradual diminution of the volume of water flowing down a river-channel. We are accustomed to see rivers varying their size in accordance with the progress of the seasons, and even shifting their channels to a very considerable degree. The marks by which we are able to recognize gradually occurring changes of volume are therefore liable to be obliterated. And as long as a lake is only an expansion of a river, while, in fact, it is in communication with the sea, its contents moving downwards with the river itself, only more slowly in consequence of its greatly increased cross-section, so long any diminution of its volume which may take place, unless it is very marked, will be likely to escape notice. But let the lake be cut off from its connection with the ocean, and become isolated, by the increase of evaporation over precipitation, and the progressive stages of a gradually lessening area will become very marked phenomena, for the very causes which conspire to bring about this condition of things are such as tend to preserve the records of their occurrence, which take the form of ancient shore-lines, beaches, and terraces. A secular increase of volume, in the case of both lakes and rivers, is naturally more difficult to make out than a diminution, because the rising waters conceal the work of former ages. Forests, if submerged, gradually decay and leave few traces behind. The works of man, on the other hand, are sometimes of a very enduring character; but, of course, testimonials to change of water-level depending on human agencies can only be furnished under exceptionally favorable circumstances, and for the very latest historical periods. The great body of evidence going to show a diminution of the water on the earth is therefore furnished by the great closed basin regions of the world, — those of Western North America and of Central Asia. Not that other countries do not offer abundant testimony corroborative of the facts specially made evident in the regions mentioned. On the contrary, the body of facts which might be brought together, did space permit, is abundantly comprehensive in character to enable us to include the whole land surface of the globe in our generalizations. We may first, however, speak of those particular proofs of desiccation which are presented within the region of the Cordilleras.

There is no body of water in the country which displays in a more marked manner the characteristic indications of decrease of size than does Great Salt Lake. Naturally, therefore, this was the first locality to attract the attention of scientific explorers. So far as known to the writer, Captain Stansbury was the first to call attention to the former much larger dimensions of this body of water. Speaking of the low land near Promontory Point, he says: "This extensive flat appears to have formed, at one time, the northern portion of the lake, for it is now but slightly above its present level. Upon the slope of a ridge connected with this plain, thirteen distinct successive benches, or water-marks, were counted, which had evidently, at one time, been washed by the lake, and must have been the result of its action continued for some time at each level. The highest of these is now about two hundred feet above the valley, which has itself been left by the lake, *owing probably to gradual elevation occasioned by subterraneous causes.* If this supposition be correct, and all appearances conspire to support it, there must have been here at some former period a vast inland sea, extending for hundreds of miles; and the isolated mountains which now tower from the flats, forming its western and southwestern shores, were doubtless huge islands, similar to those which now rise from the diminished waters of the lake." *

Here, as will be evident, the present greatly diminished area of Great Salt Lake as compared with that of former times is distinctly recognized, while the causes and conditions of this remarkable change would seem, from the statement italicized by the present writer, to have been entirely misunderstood,

* An Expedition to the Great Salt Lake of Utah. By Howard Stansbury. Philadelphia, 1852, p. 105.

it being Captain Stansbury's idea, apparently, that the mountains surrounding the lake had been elevated, and not that the lake itself had diminished, so that its water surface now stands at a lower level than formerly.

The geologists of the various Pacific railroad surveying expeditions paid little attention to the proofs of a gradual drying-up of the region under examination, and when they did observe them, they seem to have failed to apprehend their true character. Thus Lieutenant Beckwith remarks, in speaking of the terraces bordering Great Salt Lake: "They are elevated from two or three hundred to six or eight hundred feet above the present lake; and if upon a thorough examination they prove to be ancient shores, they will perhaps afford (being easily traced on the numerous mountains of the Basin) the means of determining the character of the sea by which they were formed, whether an internal one, subsequently drained off by the breaking or wearing away of the *rim* of the Basin, — of the existence of which at any time, in the form of continuous elevated mountain chains, there seems at present but little ground for believing, — or an arm of the main sea, which, with the continent, has been elevated to its present position, and drained by the successive stages indicated by the shores."*

Mr. W. P. Blake, who was attached to the party which explored the southern portion of California, and whose geological investigations are contained in the fifth volume of the Pacific Railroad Reports, published in 1856, noticed the former existence of "an extensive fresh-water lake" in the northern part of the Colorado Desert, by which term he designates the tract of country lying between the Bernardino Range on the northeast and the San Jacinto Mountains, and the connected ranges extending toward the southwest along the Pacific Coast. The area thus embraced within these lofty mountains is about 120 miles in length, narrow at its northern extremity, where it is called the Coahuila Valley, but widening out rapidly towards the south, and meeting the Colorado River near Fort Yuma. This region is almost destitute of water, the streams which find their way down the mountain slopes losing themselves before reaching the valley. A considerable portion of this area is depressed below the sea-level, as shown by the recent surveys for the Southern Pacific railroad, and there are abundant evidences, in the form of terraces, ancient shore-lines, and deposits of calcareous matter at various points, that the water of the Gulf of California once extended up nearly to the head of Coahuila Valley. The access of the sea having been cut off by the accumu-

* Report of Explorations and Surveys, etc. (Pacific Railroad Reports). Washington, 1855, Vol. II. p. 97.

lations of sand and mud brought down by the Colorado as Mr. Blake supposed, the region above the former mouth of that river became a closed basin of salt-water, which afterwards gradually became brackish, and then almost fresh, as shown by the character of the shells found at various points around its margin. Finally, the entire body of water disappeared by evaporation, and the region is now an arid desert, surrounded by detrital accumulations which slope down, in the form of "washes," from the sides of the enclosing mountains, and which for a distance of about forty miles, measured parallel with the trend of the valley, is depressed below the sea-level to the amount of a hundred feet or more. This deepest portion, however, is not that nearest the Colorado River, but is rather the upper end of the valley, the line of the railroad survey sinking to the ocean level not far from Indian Well, then continuing below that level for about forty miles, and finally rising above it again some sixty miles before reaching Fort Yuma.* In view of the facts developed by the recent railroad survey in reference to the position of the depressed area in this desert region, it would appear that the access of the Gulf must have been cut off by an actual rise of the land, and not by the accumulation of débris brought down by the Colorado.

All that part of California which lies west of the Colorado and north of the San Bernardino Range, as far as the eastern base of the Sierra Nevada, embracing an area of over 30,000 square miles, is but little better than a desert. It is traversed by broken ranges of mountains enclosing valleys, in whose lowest portions are the visible remains of former lakes, now converted into alkali-flats, which become mud-flats during exceptionally wet winters. The only one of these valleys known to be depressed below the sea-level is that forming the sink of the Armagosa River, and which is known as Death Valley, where there is an area of probably forty miles or more in length and ten or twelve in width which is from a hundred to two hundred feet below the level of the sea. As far as known to the writer, this depression and the one previously mentioned, of the Coahuila Valley and its continuation, are the only areas in North America sunk below the sea-level, and not filled with water, for the deepest of the depressions in the Great Basin proper are several thousand feet in elevation at their lowest points.

* The plan so often broached in California of inundating this depressed area by letting in the waters of the Gulf, and thus redeeming from sterility this portion of the State of California, is one of which the absurdity would become apparent to any one who would take the pains to make himself acquainted with the climatological peculiarities of the region in question. It is quite on a par with the project of converting the Sahara into an inland sea by digging a canal so as to give access to the waters of the Mediterranean.

During the progress of the California Geological Survey the evidences of the diminution of the water in the lakes on the eastern slope of the Sierra Nevada was a matter of frequent observation and comment. The terraces around the shores of Mono Lake proving its former much greater depth and larger area were described in the Geology of California, Vol. I.* (1865). The highest terrace is there mentioned as being at an elevation of 680 feet above the present level of the lake. The possible connection of Mono with Walker's Lake, in past ages, is suggested, and the probable connection of these ancient greatly expanded lake-areas with the phenomena of extinct glaciation insisted upon. The subject was brought up again in the Yosemite Guide-Book † (1869) in the following words: "That there was formerly a much greater precipitation of moisture on the eastern side of the Sierra than there now is, seems proved by the former greater extension of the lakes on the eastern slope. Mono Lake, for instance, is surrounded by terraces or benches, which show that its surface once stood 600 feet higher than it now does, and the same is true of Walker, Pyramid, and the other lakes on that side of the Sierra. No doubt at that time the now arid valleys of Nevada were beautiful inland seas, which filled the spaces between the lofty parallel ridges by which that State is traversed. Perhaps the slopes of those ridges were then clothed with dense forests, offering a wonderful contrast to the present barrenness of the ranges, and the monotony and desolation of the alkaline plains at their base."

The somewhat elaborate and very costly surveys and explorations carried on, since the stoppage of the California State Geological Survey, in the region of the Cordilleras, under authority of the United States, have developed a large body of facts additional to, and corroborative of, what had been previously stated by the present writer in respect to the great diminution in the area of the lakes of the Great Basin and of the Cordilleras in general. Mr. G. K. Gilbert seems to have been the first person to go into any detailed description of the phenomena in question, and his remarks will be found in the volume of Geology published by the Wheeler Survey.‡

Mr. Gilbert adds his testimony to that previously accumulated in reference to the absence of any proofs of a movement of the detrital materials on the

* Geology of California, Vol. I. p. 451.

† The Yosemite Guide-Book: A Description of the Yosemite Valley and the Adjacent Region of the Sierra Nevada, and of the Big Trees of California. An official publication of the Geological Survey.

‡ See Report upon Geographical and Geological Explorations and Surveys West of the One Hundredth Meridian, in charge of First Lieut. Geo. M. Wheeler, Vol. III., Geology. Washington, 1875.

surface in any one general direction. He remarks on this point as follows: "The unruffled repose of all such unconsolidated beds in Nevada and adjacent Utah is proof positive that no general glaciation has prevailed. . . . . We may conclude, without reservation, that the great ice-field of Eastern North America had no counterpart in the same latitude at the West." After describing some of the phenomena of former local glaciation about the crests of the highest ranges in Nevada, his results and inferences agreeing in the main with those of the present writer and of the geologists of the Fortieth Parallel Survey, Mr. Gilbert goes on to speak of the diminution in area of Great Salt Lake and of other bodies of water in the Great Basin. These changes he describes in a chapter entitled The Glacial Epoch, remarking that "for reasons which will appear in the sequel" he has "come to regard as phenomena of the Glacial epoch a series of lakes, of which the beaches and sediments are to be found at many points in the Great Basin." He then proceeds to indicate, in considerable detail, the former outline of Great Salt Lake at the period of its greatest extension, and to the ancient lake thus bounded he gave the name of Bonneville, in honor of the earliest explorer who brought back any authentic account of the Great Basin region, and of Great Salt Lake in particular. The work of the Fortieth Parallel Survey having superseded that of the Wheeler Survey in this region, it will not be necessary to give any detailed account of Mr. Gilbert's observations, but only to state the reasons why this geologist described the phenomena in question as belonging to the Glacial epoch. On this point he remarks as follows: "The Bonneville epoch [meaning the time when Salt Lake was much larger than it now is] and the Glacial epoch were alike climatal episodes, and they occurred in the same general division of geological time, namely, the division of which modern time is the immediate sequel.* . . . . To account for the origin of Bonneville Lake, we need to assume a climatal change that would increase precipitation or diminish evaporation; and both of these effects would follow, in accordance with familiar meteorological laws, if the humidity of the air were increased, or if the temperature were lowered. There can be no doubt, then, that the great climatal revolution, which covered our Northeastern States with ice, was competent to flood the dry basin of Utah; and that it actually did so is at least highly probable."

* Mr. Gilbert omits to mention the fact that this connection of the increased area of the Great Basin lakes with the phenomena of past glaciation had been pointed out ten years earlier by the present writer, in the Geology of California, Vol. I.

In point of fact, Mr. Gilbert, in the communication from which the above extracts have been made, adds but little to what was previously known in regard to the phenomena of desiccation in the Great Basin region. He confirms the previously observed fact of the former much greater size of Great Salt Lake, and adopts the view maintained by the present writer, several years before, in regard to the climatic character of the change, and its connection with the Glacial epoch.

The Fortieth Parallel Survey, under the direction of Clarence King, added much more to our knowledge of the facts connected with the desiccation of Great Salt Lake, as well as of other portions of the regions west of the Rocky Mountains.* Some of the theoretical views advocated by the chief of that Survey, in his volume resuming the geological results of that great work, will be noticed further on: at present we have only to do with those facts stated by him which bear on the subject before us. But, in the first place, it will be proper to quote what is stated, as the net result of the investigations which this Survey, in regard to the former glaciation of the regions, embraced within their field of inquiry. The conclusions arrived at, and which are wholly confirmatory of those of the California Survey, are as follows: "Wherever in the Fortieth Parallel area a considerable mountain mass reached a high altitude, especially when placed where the Pacific moisture-laden wind could bathe its heights, there are ample evidences of former glacial action, but the type is that of the true mountain glacier, which can always be traced to its local source. . . . . On the drier interior parts of the Cordilleras the ancient glaciers usually extended down to between 7,000 and 8,000 feet above the level of the sea. In the case of the Cottonwood glacier of the Wahsatch, a decided exception, the ice came down to an altitude of 5,000 feet."†

But what we have to do with at present is, the evidence of recent diminution in the dimensions of the lakes of that part of the Great Basin and of the Rocky Mountains embraced within the "Fortieth Parallel area"‡ and adjacent to it. In regard to this point the information given in Mr. King's

* See Fortieth Parallel Survey Report, Vol. I., Systematic Geology, Section V., Quaternary, p. 459, *et seq.*

† In the volume quoted above a diagram is given showing that portion of the surface adjacent to the fortieth parallel which was formerly covered with ice. It forms but a very small fraction of the whole area embraced within the field of the Survey.

‡ The "Fortieth Parallel area," or the belt of country embraced within the field of Mr. King's Survey, is essentially all that portion of the Cordilleras which lies between the fortieth and forty-second parallels, and east of the crest of the Sierra Nevada.

volume is full and definite. He distinguishes as especially important two great "fresh-water lakes which occupied depressed portions of the interior drainage, — lakes whose former limits are indicated by singularly well-preserved terrace-lines traced around the ancient shores." For the eastern one of these former lakes Mr. Gilbert's name has been adopted by the Fortieth Parallel Survey; the other is called by Mr. King Lake Lahontan.* The first of these, Lake Bonneville, extended from about the parallel of 42° southward to 37° 30′, the meridian of 113° representing nearly the middle of the lake. The extreme width was in latitude about 40° 21′, where the east and west extent was 180 miles; from north to south it had a stretch of about 300 miles. The present level of Great Salt Lake is nearly 4,250 feet above the sea; that of Lake Bonneville was about 940 feet higher, making the altitude of its ancient water surface at the time of the greatest extension of the lake not far from 5,200 feet. Below the upper shore-line is a series of successively lower terraces indicating a gradual recession of the waters down to the present level. The former outlet was to the north, into the valley of Snake River, as first suggested by Mr. F. H. Bradley, and afterwards proved by Messrs. Peale and Gannett of the Hayden Survey. There were some north and south trending islands, the tops of the present mountain ranges of the region, in the lake at the time of its greatest development; but the area of water in Lake Bonneville was on the whole much less irregular than that of Lake Lahontan.

This last-named body of water, as defined by the explorations of the Fortieth Parallel Survey, extended from 41° 30′ southward to about the same latitude as the southern waters of Lake Bonneville (37° 30′). The altitude of the western lake was 4,388 feet, or about 800 feet lower than that of the eastern one, and its area was also somewhat less. Lake Lahontan included within its limits the present Walker's, Carson, Humboldt, Winnemucca, and Pyramid lakes. The united area of these is about equal to half the present lake surface of the basin of Bonneville. The outline of Lake Lahontan was extremely irregular. Indeed, but little is known of its southern continuation, and its limits in that direction could only be roughly made out.† It appears

* A map showing the position and area of these two ancient lakes, and of sundry other smaller ones, lying between these, is given in Mr. King's volume. The data for this map were in part derived from the work of the Wheeler Survey.

† Chiefly from the barometric observations of Messrs. Gabb and Wilson, who were sent by the present writer to explore the southwestern corner of Nevada in 1867.

to the writer that it is very probable that the old lake surface had a somewhat greater expansion to the south than is indicated on Mr. King's diagram.

A very considerable part of the area of Lake Lahontan was occupied by long peninsulas and islands, all of which were narrow, and had the regular north-northeast and south-southwest trend of the ranges of this part of the Great Basin. These islands rose above the surface of the water to an elevation of several thousand feet. It would be difficult to find anywhere upon the surface of the earth, at the present time, a body of water having such marked and interesting orographic features as those of the ancient Lake Lahontan.

The exact position of the former outlet of this old lake seems not to have been clearly made out. The writer agrees with Mr. King in believing that the probabilities are that it was to the south. Unfortunately the region at the southwestern corner of Nevada is one exceedingly difficult of exploration, owing to its distance from civilization and the almost entire absence of water over an area of many thousand square miles. These difficulties must be taken into consideration, when it is noticed how little is accurately known of the character of the country in this direction.

It must not be supposed, from the great attention paid by the geologists of the Fortieth Parallel and the Wheeler Surveys to the two great ancient lake regions mentioned, that these were isolated or abnormal features of the Great Basin. The whole area lying between these two great bodies of water was formerly occupied by lakes without number. The entire surface of the country is intersected by nearly parallel mountain ranges, as an inspection of any good map of the Cordilleras will show.* These often rise to the height of several thousand feet above the adjacent valleys, which are usually narrow in proportion to their length, and separated from each other by low divides. These valleys are not always distinctly terraced; but they have, beyond doubt, been formerly occupied to a greater or less extent by bodies of water. Some of these were isolated and of small dimensions; others were in connection with similar lakes or lake-like expansions of the rivers, perhaps in some cases forming bodies of water of very complicated outline. It will be a long time before explorations have been made in this region in suffi-

* See map of California and Nevada, by the State Geological Survey of California; and also the one entitled "Cordilleras" in the Atlas accompanying the Fortieth Parallel Survey Report; this latter was drawn by Mr. Freyhold, and it is by far the best general map of the western side of the United States yet issued.

cient detail to fix precisely the boundaries of all these ancient lake systems. There can be no question, however, in regard to the main point, namely, that the Great Basin was once covered in large part by water, which formed lakes of various dimensions but of complicated outline, some of which were equal in area to the Great Lakes of the eastern side of the continent. The present aspect of the region in question is one of extreme aridity. The existing lakes do not occupy one tenth part of the area formerly covered by water. They are not bodies of fresh water; but are saline and alkaline, as must necessarily be the case in a region where evaporation is in excess of precipitation, and where there is consequently no drainage of superfluous water to the sea. No one can doubt that we have here evidences of an important climatic change occurring in later geological times, and in regard to which several interesting questions suggest themselves, having reference to the epoch of this change, its duration, and its relation to other manifestations of a similar character, or at least leading to similar inferences in their application to the topics up for discussion in the present volume. These questions, however, it will be best to defer until more facts have been brought forward from other portions of the Cordilleras, outside of the limits of the Great Basin.

Next to the Great Basin proper, British Columbia may perhaps be regarded as offering the most remarkable indications of a change in climatic conditions during the later geological periods. As already mentioned, the streams throughout that part of the country embraced between the Rocky Mountains and the Coast Ranges, north of the United States boundary line, are bordered with numerous terraces, which remain in perfect preservation, and prove beyond the possibility of doubt that the amount of water carried off to the sea was vastly larger than it now is. The streams at the present time are often almost a continuous succession of lake-like expansions; but this peculiar phase of fluviatile conditions as now exhibiting itself in British Columbia is but a faint shadow of what it formerly was. We have at present but little idea of the depth of the lakes in this region: there cannot be much doubt, however, that some of them will be found to occupy depressions sunk to considerable depth below the level of the surfaces of the rivers themselves. The valleys are manifestly orographic in character; and, that being the case, portions of these are likely to be very deep, where so situated as not to have become filled up with débris. British Columbia exhibits, then, at the present time, a transition stage between almost complete inundation, and entire desiccation such as is now presented in parts of the Great Basin. Let the desiccation continue and the drainage to the sea be cut off, then only the deeper portions of the lake-like expansions of the rivers would remain; and, if the climatic conditions did not change, but still favored diminution of the water, we should finally have the alkaline flats and salt lakes of the Great Basin only remaining. The disappearance of the glaciers and the formation of the terraces are the preliminary steps to such a condition.

The whole region of the Cordilleras has been from early times one highly favorable, in its orographic conditions, to the development of lakes. A great plateau-like area traversed by numerous ranges of mountains of course necessitates a system of valleys of corresponding complexity. If we imagine the corrugating forces to act always in one direction, and with uniform force, these valleys would not be likely to possess the necessary conditions for the formation of extensive lake systems; the depressions between the ranges would be parallel to each other and would not vary much in depth in their different portions. If the uplifting force died out equally in both directions from the centre, the result would be a system of valleys draining both ways from the highest point of the convex surface. If, on the other hand, the whole uplifted mass sloped one way, the waters would necessarily flow toward one side in preference. But if we suppose a force tending to produce a corrugation of the surface, and acting transversely to that which has preceded it in point of time, it is evident that the result will be that the valleys will be broken up into sections having different elevations above the sea-level. We might suppose a secondary corrugation of this kind carried so far as to almost obliterate the previous one, or at least to become the dominant system; but this seems to have been rarely if ever the case in nature, for a certain persistence in the direction of the mountain-building forces seems to have been maintained in all the great chains, even where these continued to be developed during several successive geological periods. It has been stated in the Auriferous Gravels* that there was proof that the Sierra Nevada has undergone a certain amount of thrust, or been subjected to the pressure of forces acting in a direction longitudinal to the trend of the range itself. The form of the valleys throughout the Great Basin indicates a similar condition of things to have existed there in former geological ages, and there can be little doubt that the depressions afterwards occupied by lakes owe their origin to this cause. Here, then, we have a good illustration of the differ-

* See Auriferous Gravels, p. 49.

ence, as affecting drainage, between simply-acting orographic forces and complex ones.*

Proofs of desiccation similar to those offered in the region of the Great Basin are not wanting in any portion of the Cordilleras. But when we come to examine in detail the surface geology of the country, we find that there is some difficulty in drawing the line between the phenomena indicating a diminution of the water surface as something now in progress, and those which connect themselves with similar events belonging to a former geological period. In other words, assuming for convenience the existence of a distinctly marked Glacial period, we have to deal with a Pre-glacial as well as a Post-glacial desiccation. All the facts to which reference has been made above as being exhibited around the shores of Great Salt Lake and other bodies of water in the Great Basin, we have no hesitation in referring to the latest geological period, the Post-glacial; and we even go further, and unhesitatingly connect them with the present epoch, considering that the drying-up is something now in progress. But, at the same time, a desiccation which has been going on during the latest geological period, and is even continuing at the present day, may have been begun considerably earlier; during the Pliocene epoch, or even before that. That this is the case throughout the whole region of the Cordilleras, there is abundant evidence; and even a limited investigation of the geology of the North American continent is sufficient to convince the observer that in seeking for proofs of a diminution of water-area throughout the country, we have to do with a phenomenon which belongs to the past as well as to the present. Some preliminary observations will be necessary, however, before proceeding further in this direction.

There are evidently two quite distinct phases in connection with the diminution of water area on the earth's surface; one we may designate as orographic, the other as purely climatological. But it must be borne in mind that every orographic change is liable to bring about climatic ones. This point will come up for discussion further on; at present it is only necessary to remember that every new aspect of the earth's surface, whether area or altitude of the land-masses be thereby affected, is attended by some new features of wind or ocean currents, resulting in corresponding changes of climate in the regions concerned. By the orographic phase of the desiccation process we mean, then, to indicate a local change of condition, brought

* See *ante*, p. 13.

about primarily by crust movements, in contradistinction to such as might result from more general causes, of a nature to affect the whole earth's surface. For instance, we might conceive of such an elevation of a part or the whole of the plateau of Central Africa as to cause the draining off of a large portion of the many thousand square miles of area at present covered by water in that region. Such a change of altitude of a considerable mass of land would undoubtedly produce climatic changes to some extent; but the diminution in the lake area would not have had primarily a climatological cause. If, on the other hand, we conceive the surface of the land to remain at its present height and to be otherwise unchanged, but that, for some reason, the rainfall in the tropical regions is diminished, then evaporation would gain on precipitation and the area covered by water would diminish permanently, instead of varying temporarily, as it would otherwise do, in harmony with the ordinary fluctuations of the seasons.

Thus, then, if we find that there has been a great diminution in the area covered by water on the western side of this continent during the later geological ages, we have to inquire how far this may have been due to an upheaval of the land, and how far to a purely climatological cause. This is by no means an easy task, and it is this very fact which makes the kind of evidence in regard to desiccation furnished by a region like that of the Great Basin, or of Central Asia, as will be stated further on, of so much value, as indicative of a change of climate independent of any orographic cause. Bearing these considerations in mind, we may now proceed one step further in the present investigation.

The combined investigations of all the geological surveys carried on west of the Mississippi during the past twenty years make it evident that there have been great changes in the relief of the surface in that region during the later geological periods. The present writer, however, is clearly of opinion, after a careful review of the whole body of published facts and a personal inspection of a considerable portion of the area in question, that there has been no essential alteration in the configuration or topography of the western side of the continent since the Glacial epoch, — that is, since the time when the crests of the highest ranges were, to some extent, covered with snow and ice. Therefore, no part of the desiccation proved to have taken place since that time can be due to orographic changes; the phenomenon must have been a climatological one.

But during the Tertiary period vast areas of the region between the

Rocky Mountains and the Sierra Nevada were covered by fresh water, forming interior lakes, the exact dimensions of which have not yet been made out, but of which enough has become known to convey a vivid idea of the existence of a lacustrine development surpassing in magnitude anything now existing on the earth's surface. For reasons which will be readily appreciated, our studies of the relative areas covered by land and water at different geological times must be limited to the occurrence of fresh water. We are not quite advanced enough in this discussion to take up the question of the changes of climate which have been continually going on during the geological times in consequence of the ever-increasing area of the land masses and the diminution of the ocean surface. We know from the investigations of the various surveys carried on in the Cordilleras, that the ocean has been shut out from a large part of the region between the Rocky Mountains and the Sierra Nevada for a long period, including certainly the whole of the Tertiary epoch. Indeed, there are no Cretaceous rocks between the Wahsatch Range and the crest of the Sierra, so that, in all probability, the sea has not had access to any part of the belt between the 112th and 120th meridians since the close of the Jurassic epoch. The extent of this belt over which no marine Cretaceous or Tertiary is found, in a north-south direction, is not as yet exactly known. It appears to extend, however, some distance to the north of the boundary of California. We have, then, two enormous areas, to one of which the sea has not had access since the close of the Jurassic epoch, and to the other not since the end of the Cretaceous. The depressions throughout these regions have, therefore, been so situated as to become the recipients of detrital accumulations, either of subaerial origin or lacustrine in character. The lithological character of such materials would of course vary considerably in different portions of the regions, according to the nature of the conditions presented by the areas of depression and the surrounding elevated ranges. Of the accumulated masses of material much would naturally remain concealed by more recent deposits; but in many places a large amount of erosion has so exposed the strata as to furnish excellent chances for examining them. The large lacustrine basins are filled with deposits of detrital material which in places have a combined thickness of several thousand feet. Since the geological age of these formations could only be made out by the aid of fossils, it is fortunate that in the region west of the Rocky Mountains they are frequently abundantly supplied with these essential guides to the geological relations of the various members of the series. Of course these fossils are the remains of land or fresh-water animals and plants; and so great is their number and so various and extraordinary their character that their investigation, in the hands of Professor Marsh especially, has furnished one of the most interesting and important contributions ever made to the science of palæontology in any country. The study of the lithological characters of the detrital materials can hardly fail to throw light on some of the obscure points in the geological history of the region in question; but as yet the data are so imperfect that much must be left undecided.

All the principal divisions of the Tertiary epoch are represented in the lacustrine accumulations of the Cordilleras; but the older members occupy much more space than the newer. The Eocene is represented chiefly in the region lying between the Rocky Mountains and the Wahsatch Range. The lowest member of this division of the Tertiary has, according to the investigations of the Fortieth Parallel Survey, a maximum thickness of about 5,000 feet, consisting chiefly of rather coarse sandstones, with intercalated clayey layers, the formation containing coarser materials near the ancient shores. The fossils are mollusks in abundance, with a few fishes, and a wonderful variety of other vertebrates. For this oldest of the Tertiary lakes of this region Mr. King has proposed the name of Ute Lake. This body of water filled the entire Green River basin for a distance of 150 miles north of the fortieth parallel, and with an unknown extension to the south, but probably for 200 miles farther in that direction, making its total length 350 miles or more; its breadth must have reached 150 miles. During the period of the existence of this body of water the Uinta Range formed an island in it, not far removed at its western end from the main-land, and it was from this quarter that the detrital material which was deposited in Ute Lake chiefly came. After the accumulation of the beds (the Vermilion Creek series) which form the base of the Eocene, within the limits of the depression indicated above, Mr. King considers that a period of orographic disturbance ensued, as the result of which an extensive area of the adjacent land on the west was depressed, so that the breadth of the lake was doubled. As thus enlarged it extended west to the 116th meridian. The rocks deposited over this newly formed area of depression consist chiefly of fine-grained shales and marls, containing many remains of fishes and fresh-water mollusks, besides a few beds of lignite. Over these shales is a heavy deposit of ferruginous sandstone. The enlarged Ute Lake, called by Mr. King Gosiute Lake, diminished in size in consequence of orographic disturbances combined probably with climatic changes, and a new sheet of water resulted; this was situated wholly within the boundaries of the former Ute Lake, and it was succeeded by still another, each being characterized by its special Fauna. Of the precise limits of these bodies of water little has as yet been made out; but the deposits laid down beneath their surfaces contain an abundance of the most interesting vertebrate remains, all considered by Professor Marsh to belong to the Eocene. At the close of this period great orographic disturbances took place over the Cordilleras, which resulted in the drainage or extinction of the Eocene lakes, over whose surface no Miocene deposits are found, indicating an important palæontological break at this period, and great changes in the relative area of land and water throughout this portion of the country.

The orographic disturbances which marked the extinction of the Eocene lakes, as indicated above, gave rise to new areas of water, into which detrital materials were carried in abundance, forming deposits of great thickness and extent, replete with interesting vertebrate remains. The Miocene lacustrine areas seem to have been two in number. One of these was of vast extent, and was situated to the east of the Rocky Mountains. Here, on the depressed and eroded surface of the underlying Cretaceous strata, over the region now known as "the Plains," an immense sheet of water existed during the Miocene period, including the White River lake-basin of Hayden, which extended along the eastern slope of the range, from the parallel of 40° far to the northeast, beyond the limits of the United States into British Columbia. The other lake was situated to the west of the 117th meridian and east of the Cascade Range, in Central Oregon.

The deposits of the Miocene period in the Eastern basin have a thickness of a thousand feet or more. On White River, where they have been eroded into the most curious and fantastic forms, they give rise to that peculiar type of country known as the Bad Lands (Mauvaises Terres). Here, also, the strata are crowded with interesting fossils, all of which are the remains of animals or plants living on land, or in and near fresh water, and which have been described and figured by Leidy and Marsh. The sediments of the Oregon Lake were of great thickness, equalling at least 4,000 feet, and being made up in large part of volcanic materials either ejected from under the surface of the water or washed into it from the surrounding volcanic summits. The abundant fossils found in this region also indicate the absence of the ocean, and the Miocene character of the Fauna.

As we ascend in the geological series to higher groups, the difficulty of separating the past from the present offers an obstacle to generalizing. It is often impossible to say what is Pre-glacial and what Post-glacial. There has been no sudden change in the Fauna which would afford a guide to the classification of the more recent deposits. Some of the characteristic Pliocene species seem to have lived on to quite a recent date; and, although now certainly extinct, it is not safe to say that some of them may not have become so almost within the historical period. These points, however, are not of vital consequence in connection with the present discussion. What is particularly desired here is, proof of an area of water surface over the western portion of this continent diminishing with the progress of geological time, which is not difficult to procure; and proof also that this diminution has been the result of climatological as well as orographic causes, this latter branch of the inquiry being by no means as simple as the other.

It seems clear, however, that, so far as the region west of the Rocky Mountains is concerned, if there was not much less water surface on the whole during the later Tertiary times, there were, at least, no such great lacustrine areas as existed during the Eocene and Miocene epochs. Lakes Bonneville and Lahontan were large, but not in comparison with Ute and Gosiute lakes. So, too, the Pliocene lake-areas would not compare in size with the bodies of water which preceded them in the same region. The largest unbroken area of Pliocene lake surface west of the Rocky Mountains seems to have been in the North Park region, occupying nearly the whole of that valley, and extending along the North Platte up to latitude 41° 30′ or farther. Here, resting on the Azoic rocks, is a thickness of a thousand feet or more of sandstones of varying degrees of coarseness capped with marls, the whole of which formation is referred by Mr. King to the Pliocene, although fossils seem to be wanting. Much is of course concealed by the later Post-pliocene or Quaternary deposits.

Beyond, a very considerable extent of surface was no doubt occupied by water during the Pliocene epoch; but the deposits of that age being so largely covered with later ones, the exact limitation of the Pliocene lake-areas cannot possibly be indicated. The present Humboldt Valley seems to have been one of these old basins, and this probably had ramifications extending north and south between the ranges, so as to form an extensive water surface of complicated outline like that of the former Lake Lahontan. Some few fossil remains were found in this region, indicating the Pliocene age of the formation, and the close relations of its Fauna to that of the Niobrara Group east of the Rocky Mountains. It may be taken for granted that in all the valleys of the Great Basin, where there are proofs of the existence of water during Quaternary or Post-glacial times, there must have been lakes during the earlier Tertiary periods, although the conditions might not have been favorable to the development of organic life in such localities, for it is easily seen that large lake-areas in broad valleys would be much more favorably situated for the growth of animals and plants than narrow and deep valleys, into which coarse sediment was continually being carried by streams descending the steep slopes of the adjacent ranges. As being in harmony with these considerations, it cannot fail to be noticed how comparatively poor in fossil remains are the deposits accumulated, largely by rapid river-action, on the west slope of the Sierra Nevada, and how rich, on the other hand, are those broad lake-basins of the earlier Tertiary period, farther east in the Cordilleras.

The region east of the Rocky Mountains, included within the area of the Plains, was undoubtedly extensively covered by water during the Pliocene epoch. The precise limits of this immense lacustrine area cannot at present be given. It is known, however, that it bordered close upon the base of the Rocky Mountains on the west, and extended into Kansas in the opposite direction. North and south it stretched from Texas to far beyond the United States boundary-line. Of course over this vast area the thickness and character of the deposits are very variable. Near the elevated range on the west the accumulated débris would necessarily be greater in amount and coarser in character. Fossils have been found in many localities, the remains of the mammalia being of the most interesting character. This Pliocene lake-area was obliterated by the latest orographic disturbance which gave their present form and altitude to the Rocky Mountain ranges. The overlying Pliocene with all the underlying deposits have all been raised bodily from the western edge, in a simple uplift without thrust or fold, so that the net result, as respects drainage, is quite unlike that which manifested itself farther west. On the eastern side of the mountains there is an extremely gradual and constantly diminishing slope down to the Mississippi Valley, without any lakes whatever; while on the other side the original corrugations in the older rocks have not been so entirely obliterated, by filling with detrital materials, that there is not ample opportunity for the accumulation of large bodies of water, if only the climatic conditions were favorable. Did, however, such depressions exist on the eastern side of the Rocky Mountains, in the region of the Plains, it is very doubtful whether they could be kept filled with water, since the precipitation is quite small.

That most elevated belt of the Rocky Mountains comprised within the so-called Parks, beginning at the San Luis Park, and extending to the Laramie Plains, a region having an altitude of from 8,000 to 10,000 feet, has been more or less occupied by water up to quite a recent period. North Park has already been mentioned in this connection. San Luis Park, however, is much the largest of the comparatively level areas designated by this term. It is about a hundred miles in length, and from twenty to thirty in breadth. Professor Stevenson * considers that this whole area "was at one time occupied by a great fresh-water lake covering an area of several thousand square miles and fed by streams coming from the mountain glaciers." Mr. Endlich,† in describing the same region, quotes Professor Stevenson's remarks, and adds: "Essentially this statement agrees with my own observations." The evidences of terraces seem to be rather obscure; but the whole aspect of the Park is that of an area covered in large part by water at no very distant period. Mr. Endlich came to the conclusion that there were formerly two large lakes here; one of 1,400, the other of 300 square miles of area. The Rio Grande enters San Luis Park on the west side, and leaves it at the south end, passing through a deep cañon of basaltic lava. Between the former lakes, one of which occupied the northern and the other the southern end of the Park, there is a mass of volcanic rock, through which the river has cut a deep cañon, and Mr. Endlich considers that the water of the two lakes was drained off by the formation of fissures in the lava, which gave the river an unobstructed exit. He also thinks that if the outlet thus produced were now to be closed a new lake would be formed. This supposition must be based on the idea that the Rio Grande drains such an extensive high mountain area that its volume would be more than sufficient to overcome the evaporation. This, however, appears to the writer somewhat doubtful, since the streams at present coming into the northern end of the Park from down the slopes of the lofty Sangre de Cristo and Sierra Blanca ranges do not succeed in maintaining themselves against the evaporating tendencies, so as to reach and join the Rio Grande. The upper part of the Park is, in short, an arid, sandy region, but little better than a desert in its aspect.

* Wheeler's Reports, Vol. III., 1875, p. 462.

† Hayden's Report for 1875, p. 149.

SECTION III. — *Desiccation of the Asiatic Continent, and of other Portions of the World.*

Having given an account, in the preceding section, of the phenomena of desiccation in the region of the Cordilleras, it might seem but natural that the eastern side of the North American Continent should next be taken up, and considered from the same point of view. But when we come to examine the geological conditions exhibiting themselves in the region east of the Mississippi, and in the vicinity of the Great Lakes, we find that we have to deal with quite a different set of phenomena from those presented on the western side of the continent, and that these introduce new complications into the question of desiccation, rendering the understanding of the problems involved considerably more difficult than we have found to be the case in the discussion of the decrease of the water-surface in the Cordilleras. For this reason it seems best to defer the consideration of the geological facts indicating desiccation in Eastern and Northeastern America until another chapter, when they will be taken up in connection with a discussion of some of the general principles involved in desiccation and glaciation. For the present it will be more satisfactory to pursue our review of the phenomena indicating decrease of precipitation in a region more closely allied in character with that which forms the subject of the preceding section than is the eastern side of our own continent.

The portion of the earth's surface to which we now turn is the Asiatic Continent; and here we find ourselves in the presence of conditions extremely similar in character to those which have been described as manifesting themselves in the Cordilleras; but on a grander scale, and also vastly more important in their relations to the past history, if not to the future welfare, of mankind. It will become evident, from the facts presented in this section, that Asia has been the scene of great physical changes during the most recent geological times; that of these no inconsiderable portion has taken place within the historic period; and that — as there is good reason to believe — the development and migrations of great nations have been most powerfully influenced by these changes.

In the entire continental mass of Europe-Asia (Eurasia, as it is sometimes and very conveniently called, the separation between the two divisions being a purely artificial one) we have, in round numbers, twenty-one million square miles of territory,* of which a little over seventeen millions belong to Asia proper, this being considerably larger than the combined area of North and South America. Here, too, we find the largest existing area of land without drainage to the sea, forming a series of closed basins, of which the entire area is probably not less than three million square miles. This closed-basin area is, in most respects, closely analogous to our own Great Basin, but is on a much larger scale. Like that, it is intersected by numerous more or less independent chains of mountains, which enclose valleys, sometimes narrow and limited in length, and in other cases of vast dimensions. Often each one of these valleys forms an independent basin; then again several are connected together into one drainage system. An exactly similar condition prevails in our own Great Basin, in the driest portion of which each separate valley is usually closed at both ends, as is the case with so many of the depressions between the ranges in Southern Nevada, — while in other cases an area of considerable magnitude may be drained towards a central depression by means of one or more transverse breaks, crossing several ranges, as is the case with the valley of the Humboldt River, and the various side-valleys more or less perfectly connected with it.

The Asiatic closed-basin region is centrally situated with respect to the continental mass to which it belongs; while that of North America occupies an area of an irregularly triangular shape, the southwestern corner of which comes close to the Pacific, forming, in fact, a part of the Pacific slope, since it is entirely surrounded by streams all of which empty into that ocean, — for the branches of the Colorado and the Columbia head entirely to the east of the Great Basin. In Asia, on the other hand, the drainage from the central, elevated, and closed-basin region is radial, towards the Northern Ocean, the Indian Ocean, and the Pacific. And so vast is the continental mass that, in spite of the immense size of the closed-basin area, the rivers descending from its elevated borders, and flowing in each of the specified directions, are of great size, so that a large number of them may be classed as rivers of the

* The estimates of the areas of the various continental land masses, given in the text-books of geography, differ from each other in the most surprising manner; that of Asia being especially uncertain, the figures in regard to that country varying from fourteen to eighteen million square miles. The latest and most trustworthy authority (Behm und Wagner, in Ergänzungsheft, No. 62, 1880, to Petermann's Mittheilungen) gives the area of Asia at 44,572,250 square kilometers, equal, in round numbers, to 17,200,000 English square miles. By the same authority Europe is given at 9,710,340 square kilometers, equal, in round numbers, to 3,750,000 English square miles. The combined area of Eurasia is, therefore, in round numbers, 20,950,000 square miles. The area of America (North and South) is put down by Behm and Wagner at 38,389,210 square kilometers, or 6,183,040 square kilometers less than that of Asia (2,387,000 English square miles).

first magnitude. Only in the southwestern portion of the continent is there an almost entire absence of large streams; as is easily understood when the peculiar position of this region with reference to the system of the trade-winds, and the proximity of the continental mass of Africa, are taken into consideration. And this region may properly be the first to be taken up for investigation as to its possibly changed condition during historic times, and during the period immediately preceding them.

From an examination of the facts it appears certain that the whole region adjacent to the Mediterranean, both in Asia and Africa, — and, to a more limited extent, in Europe, — has been, and still continues to be, the scene of climatic changes, which have been more important than any taking place on the earth's surface, in their effect on the well-being of the human race. Here History goes back farthest with her records; here remain authentic monuments, of various kinds, testifying to facts which more or less directly bear on the question before us, and justify us in believing that one of the most prominent causes of social changes, and of the migration and decay of races and peoples, in those countries, has been the constantly increasing desiccation of the region in question — a region which embraces the area to which the earliest real intellectual development of the human race was, so far as history is concerned, almost exclusively confined.

It appears to be an established fact, that the region extending from the western extremity of the Himalayas, through the valleys of the Euphrates and Tigris, Arabia, Palestine, Greece, Egypt, and the whole extent of the southern shore of the Mediterranean, and, in a more limited degree, the countries on the northern shore of that sea, have been inhabited by a very much denser population than that which at present occupies them; and it also follows, almost as a matter of course, that, with this diminution of their population, these countries have lost almost all the importance which they once had. It is quite unnecessary, and it would be here out of place, to do anything more than recall the well-known fact that the various nations included within the area bordering on the Mediterranean have, at various times in the past, either consecutively, or with more or less overlapping of rising with declining nations, ruled the portion of the world which had the best claims to be called civilized — and this both by force of arms and by force of superior intellect.

That no one of the nations inhabiting the region in question exercises, at the present time, any dominating influence over the intellectual development of the world, is an admitted fact. But it is possible to go much farther than this, and to say, that over extensive regions, where once the light of civilization shone with its brightest effulgence, and both the arts and the sciences had acquired a remarkable development, there now a scanty nomad population, living from hand to mouth, without a single attribute worthy of respect, just drags along a miserable existence, continually struggling against the forces of nature, and palpably losing ground from century to century. Let the reader, for instance, contrast the present condition of Arabia with its former one, when it led the van of scientific inquiry, and he will have a good illustration of the kind of change to which the writer is here making reference.

That the cause of this immense going backward of the region to the east of the Mediterranean is exclusively physical in character is not intended to be asserted; but that there is a physical cause which must have had a most powerful effect in bringing about the condition of things here indicated is beyond a doubt. It admits of demonstration that the countries in question have become very materially drier than they were during the earlier historic period; and that, consequently, life is no longer possible there, except under conditions which are not compatible with density of population or with intellectual vigor.

It will not be possible, at the present time, to do more than give a few of the salient facts which support the above assertion. It may, however, be unhesitatingly declared that the evidence is abundant, and that it all points in one direction. Here, however, as in the preceding section, a full discussion cannot be entered upon. Only a few of the prominent facts can be presented, and it must be reserved for another chapter to endeavor to make out how far the phenomena of desiccation are to be ascribed to a purely climatological cause, and how far to preceding orographic changes.

Decidedly the most striking event presenting itself to us, in the region in question, as an evidence of desiccation within the historic period, is the greatly diminished area of water-surface in the Aralo-Caspian basin, a problem which has much occupied the attention of physical geographers at various times, and especially within the past half-century, the literature relating to this subject being already quite voluminous. Even to name all the authorities who have written in regard to the changes which have taken place in the physical geography of the region in question in historic and prehistoric times, with reference especially to the channels of the rivers

Amu and Syr, and the varying form and area of the water-surface of which Lake Aral and the Caspian Sea are the principal relics, would require more space than can here be allowed. The main point in connection with the subject at present before us is this: that the area covered by water in this part of Asia was once vastly larger than it now is. It is also true that this diminution has been effected — to a considerable extent at least — within historic times, and there is little doubt that it is still going on.

Humboldt seems to have been the first physical geographer to fully appreciate the interest attaching to the question of the former extension of the two inland seas, the Aral and the Caspian, and their connection with the Polar Ocean. By his citations of the ancient authors who have written on this subject, he has made it easy for more modern investigators to follow the various contradictory opinions put on record by various writers, from the time of Herodotus down to the beginning of the sixteenth century.* It was at Humboldt's request that the necessary hypsometrical determinations were made, under the direction of the St. Petersburg Academy, to determine the precise difference of level between the Caspian and the Black Seas. The same eminent authority was also the first to clearly perceive that violent catastrophes or orographic causes need not be called upon to account for the desiccation of this region, but that the phenomenon was purely a climatic one. He says: "The desiccation which is unquestionably going on in the basin of the Aral Sea, and the changes which are to be observed in that long file of lakes which mark the traces of a channel [sillon] from the Aksakal Barbi to the pools [mares] of the Baraba steppe (the remains of the Bitter Sea of the Chinese Annals), are in no way dependent on any violent revolution in the order of nature. They are simply the effects of the want of equilibrium between evaporation and the volume of water brought in by affluent streams and by atmospheric precipitation. They are quite of another character from the cataclysms of Fo-hi and Yao, which are supposed to have happened thirty-five and twenty-four centuries before the Christian era." †

A more recent investigator in the same field is Major Herbert Wood, of the Royal Engineers, who devotes considerable space in his work entitled "The Shores of Lake Aral," ‡ as also in an article communicated to the

* See Asie Centrale, Paris, 1843; Vol. II. p. 156.

† l. c., Vol. II. p. 142.

‡ London, 1876. See especially Chapter X., "The Aralo-Caspian Sea," and Chapter XI., "The Caspian of History."

Journal of the Royal Geographical Society,* to the discussion of the physical changes going on in the Aralo-Caspian Basin.

To sum up the results attained by these and other investigators, it may be stated that there is no doubt of the former vastly greater extension of the combined Aralo-Caspian Seas, and extremely little as to their former connection with the Polar Ocean. While there has been much discussion, without absolute unanimity of opinion having been attained, in regard to the shifting channels of the rivers entering these seas, and their variations of volume at different times during the historic period, it seems to be beyond dispute that a gradual desiccation, extending over a vast area, has been, and still is, in progress.

Dr. Neumayr, in a notice of Professor H. Schmidt's work on the Aralo-Caspian depression,† gives the following statement as the result of his investigations of this subject.‡ "The solution of this enigma is offered by the study of the Tertiary formations of Eastern Europe and Western Asia. As is well known [bekanntlich], there existed, in later Miocene times, an immense slightly brackish inland sea, which included the basins of Hungary and Vienna, Transylvania, Wallachia, Croatia, Sclavonia, the Black Sea, the Pontus, the larger portion of the Grecian Archipelago, and the Aralo-Caspian Basin. At a still earlier epoch the region thus embraced was an immense gulf of the Northern Arctic Ocean, from which the basin in question became gradually separated. The freshening of the arm of the sea thus cut off from communication with the salt water became possible, as may be affirmed with almost certainty [ziemlicher Bestimmtheit], by means of an outlet in the direction of the upper course of the Irtysch and Obi Rivers. This immense brackish-water basin has been, ever since later Miocene times, in the condition of continuous decrease in size; and the intercalation of the glacial epoch had no effect, so far as has been yet made out, in raising its level. The separation between the Black and the Aralo-Caspian Seas must have taken place before the former became connected with the Mediterranean, as is shown by the small amount of saline matter in the Caspian; and the union of the Black and the Mediterranean Seas must be of very recent date, since the detrital deposits on the borders of the Black Sea contain

* See Journal of the Royal Geographical Society, Vol. XLV. (1875), p. 367, Art. XV., entitled "Notes on the Lower Amú-darya, Syr-darya, and Lake Aral, in 1874." By Major Herbert Wood, R. E.

† Prof. Dr. H. Schmidt, "Die Aralo-Kaspi Niederung und ihre Befunde." Leipzig, 1874.

‡ Verhandlungen der k. k. geol. Reichsanstalt, 1875. p. 31.

a brackish-water and not a marine Fauna. We therefore perceive that the separation of the region of the Pontus from that of the Aralo-Caspian Sea could only have been effected by evaporation of the water, or diminution in the volume of the affluents."*

In regard to the positive diminution of the water-surface of Lake Aral during the most recent historic times, the following quotation may be offered from Humboldt's work, to which reference has already been made. He says: "At the present time [aujourd'hui] Lake Aral, especially at its northeastern end, is diminishing in size in an extraordinary manner. The Bay of Sari-tchaghanak, for instance, extended, hardly eight years ago, to the hill of Sariboulak, now twelve leagues distant from its present bank."†

In regard to the same point Major Wood remarks as follows: "The sand dunes and tracts of hard clay occurring on the low shores of Lake Aral point to the conclusion that extensive areas of country, which are now dry land, were formerly covered by the water-spread of the lake. It has been remarked that the mouth of the Syr-darya has become, in recent years, fordable; and that the depth of water between the island of Tokmak-Atta and the north shore of Lake Aral has been diminished. It is also an established fact that a minaret, which graybeards of the Kirghiz state was formerly situated on the edge of the eastern shore, is now at some hours' walk distant from it; and finally, since 1848, when it was a marshy swamp, Gulf Abougir, at the southwest corner of the lake, has been entirely dried up, and its bed is now under cultivation. There is no doubt that the cause of this continuous shrinking in the area of Lake Aral is, that the evaporation from its surface is in excess of the supply received by it from the Amú and the Syr."‡

In describing the phenomena of the desiccation of the Aralo-Caspian Basin, Humboldt gives no reason why evaporation should so steadily have been getting the upper hands of precipitation. The object of this chapter being simply to furnish evidence of the fact of a general desiccation, the discussion of the causes of this extraordinary event is reserved for a succeeding chapter, and the reader is now invited to pass on to the consideration of similar conditions in an adjacent region.

* The importance, from the point of view of the present investigation, of the last paragraph induces the writer to repeat it in the original: "Wir sehen demnach, dass die Trennung des Pontischen vom Aralo-Kaspischen Gebiete lediglich durch Verdunstung des Wassers oder Abnahme der Zuflüsse veranlasst sein könnte."

† l. c., p. 271.

‡ Journal of the Royal Geographical Society, Vol. XLV. p. 403.

Closely adjacent to the Aralo-Caspian depression is the vast region known to us by the name of Persia, — a country containing not less than 600,000 square miles of area, much the larger portion of which is a lofty table-land, elevated from 3,000 to 4,000 feet above the sea-level. This table-land is surrounded by a ring of mountain ranges, everywhere higher than the interior, which forms a closed basin, or series of them, nearly the whole extent of country thus enclosed being an absolute desert. As Mr. Blanford remarks: "Not only is there no constant stream flowing from the interior of Persia, but no water-course communicates with the sea from the interior, and every drop of rain which falls on the Persian plateau is evaporated within its limits." * Of this vast region it can be said, with truth, that it is so dry that its population is barely able to find the means of subsistence; that this population has, on account of the dryness, greatly diminished, and is still diminishing in numbers; and that, from time to time, the most frightful famines sweep away hundreds of thousands of victims.

These facts are so well known that it will not be necessary to do more than to give one or two extracts, from thoroughly reliable sources, as illustrations of what could be furnished, in the way of evidence, in almost unlimited amount. The following is quoted from the official report of the Anglo-Persian Boundary Commission: "At every halting-place [on the road from Bushahr to Shiraz] crowds of famished, half-naked men and boys (the women and children were nearly all dead) thronged around our camp, too weak to beg, but hoping, yet hardly expecting, succour from the bounty of the infidels. . . . . On my return I took the unfrequented eastern road to Shiraz. Even here my servants buried three corpses on one day's march of thirty-five miles, during which we did not meet a living soul." †

The present population of Persia is unknown. It has been estimated at from four to ten millions. Behm and Wagner put it at "about 7,000,000." ‡ The Boundary Commission estimate the loss of life by famine, — "actual deaths from disease and starvation," — in 1870 – 71, "not to have exceeded half a million; though, from the disproportionate mortality of women and children, the ultimate loss to the country will be far higher."

According to Dr. Bellew, § the loss of life by famine in the province of

* Eastern Persia. An Account of the Journeys of the Eastern Boundary Commission. London, 1876. Vol. II. p. 449.

† l. c., Vol. I. pp. 95 – 97.

‡ Die Bevölkerung der Erde, VI. Ergänzungsheft, Petermann's Mittheil. No. 62, 1880.

§ Quoted in Behm and Wagner, VI. p. 30.

Chorassan, during the years 1870 – 72, was not less than 120,000 persons, which would be about one in seven of the entire population.

The reasons which have been assigned by various authors for the evident desiccation of Persia will, like those having reference to the Aralo-Caspian depression, come up for consideration farther on. At present, it will be desirable to give only one more quotation, from a highly scientific authority, that of W. T. Blanford, the geologist of the Anglo-Persian Boundary Commission, and the present chief of the India Geological Survey: "From the accounts given by ancient writers it appears highly probable that the population of Persia was much greater, and the cultivated land far more extensive, 2,000 years ago, than at present; and this may have been due to the country being more fertile in consequence of the rainfall being greater. Some alteration may be due to the extirpation of trees and bushes; but this alone will scarcely account for the change which has taken place. I cannot but think it probable that a gradual change in the climate of Central Asia generally has taken place from the time when the great plain north of Persia was under water, when the Black, Caspian, and Aral Seas were united, and when, as Loftus has shown, the plains of Mesopotamia were a part of the Persian Gulf, this gradual drying up of the country being thus connected with the elevation of the steppe-region of Central Asia, and of the northern coasts of Persia. To this gradual reduction in the rainfall of modern times is probably to be attributed the circumstance of the Oxus no longer reaching the Caspian, and the diminished volume of that river; for I cannot but suspect that the diversion of the Oxus from the Caspian to the Aral Sea in the sixth, and again in the sixteenth century, was but the last in a series of changes in a stream which once, in all probability, carried the surplus waters of the Aral Sea to the Caspian. To the same cause is probably due the gradual diminution of the Caspian and the Sea of Aral; and hence the disappearance of the lakes which once, I believe, covered no small part of the interior of Persia. . . . . But for inland seas and lakes to have occupied the interior of Persia, and for large deposits to have formed in them, it is evident that the climate must have been much damper than at present. In recent times the rainfall has been insufficient to supply water either to fill the basins, or, as we have seen, to wash down the detritus which accumulates at the foot of the hills."*

* See, Quarterly Journal Geological Society, London, Vol. XXIX. (1873), p. 493, an article entitled "On the Nature and Probable Origin of the Superficial Deposits in the Valleys and Deserts of Central Persia."

Evidence of similar character in regard to past and present desiccation may be gathered in abundance for regions adjacent, on the east, to those to which our attention has just been directed. The diminution of the lakes in the closed-basin region of Northwestern India, Western Thibet, and Turkestan, has been repeatedly noticed and described by scientific writers within the past few years. For instance, Hermann von Schlagintweit, in an article entitled "Investigation of the Salt Lakes in Western Thibet and Turkestan," says: "In all portions of High Asia, both south and north of the main water-shed, there are numerous places where the former existence of mountain lakes may be recognized. . . . . In Thibet, throughout the entire longitudinal depression between the chain of the Himalayas and the main water-shed of the Karakorum, of the once numerous lakes but comparatively few are in existence. . . . . So extreme is the dryness in Western Thibet, that in the case of nearly all the lakes still remaining, the evaporation exceeds the present supply of water, so that the prevailing condition is at the present time one of gradual diminution in the area covered by water." *

The evidence furnished by the Geological Survey of India is to the same effect as that previously obtained by the Schlagintweit brothers. A portion of this evidence is thus summed up in the official *résumé* of the work of that Survey: "All around these lakes and lake-plains [of the Central Himalayas] there is clear evidence that the waters once stood at a much higher level. This fact points to a continuance of the cause which once gave rise to these lakes, — a progressive decrease of precipitation and increase of evaporation, whereby the carrying power of the streams has become more and more out of proportion to the rate of disintegration of the rocks." †

The observations of Mr. Drew, the author of an elaborate work on Jummoo and Kashmir, ‡ fully corroborate the previously entertained idea that the latter valley was once occupied by a large lake. This writer says: "The observations of nearly every traveller to Kashmir have tended to show that the Vale was in late geological times completely occupied by a lake. The traditions of the natives — traditions that can be historically traced as having existed for ages — tend in the same direction. . . . . The existence of a

* Proc. Bavarian Acad. of Sciences, Cl. II. Band XI. Abtheilung I.

† A Manual of the Geology of India, chiefly compiled from observations of the Geological Survey. By H. B. Medlicott and W. T. Blanford. Calcutta, 1879. p. 672.

‡ The Jummoo and Kashmir Territories. A Geographical Account. By Frederic Drew, F. R. G. S., F. G. S. London, 1875.

lake over the whole valley of Kashmir occurred at no remote time, speaking by a geological standard; but it was long enough ago to have preceded any of the monuments of man that have yet been discovered." The area which must have been covered by water "at no remote time" was about 2,000 square miles.

In continuing our observations of the phenomena of desiccation in an easterly and northeasterly direction from the region just passed over in review, we find ourselves confronted by facts of a similar character to, and on quite as grand a scale as, those described in the preceding pages. Want of space makes it impossible to do more than offer a few citations from the works of the most eminent modern explorers of the arid regions of Central High Asia.

The mountains of the Thian-Schan, a great complex of ranges stretching off to the northeast, in parallel alignment, from the so-called Pamir Plateau, and forming the crumpled border of High Asia on its northwestern side, have been recently explored, in considerable detail, by Sewerzoff, who thus expresses himself, when speaking of the distribution of forests on the ranges in question: "Be this as it may, the fact that many forests which have been destroyed are never replaced shows that these forests were developed at a time when the climate of the Thian-Schan was moister than it now is; and that it was once moister is proved by traces of former glaciers and lakes which have now disappeared, as well as by the fact that Issyk-Kul (Lake Issyk), which has no outlet, has materially decreased in size, as is proved by the position of the sedimentary deposits which surround it, and reach an elevation from 300 to 500 feet greater than that of the present surface of the lake."*

The author of "The Indian Alps" † (Mrs. Mazuchelli) makes similar remarks with regard to the portions of the Himalayas traversed by her party. According to her, the pines in the higher regions are all dying out, and no young ones are growing up to supply the deficiency. No mention is made of desiccation as a possible cause of this condition of things, in this case, but it would seem that this must be the chief one. In many parts of the High Sierra, in California, the writer has observed similar facts, indicating that the growth of trees, along the upper limits of arboreal vegetation, is disappearing, never to be replaced. ‡

* Petermann: Ergänzungsheft, No. 43. 1875. p. 67.

† The Indian Alps and How we crossed them. By a Lady Pioneer. London, 1876.

‡ See also, on this point, C. King's "Mountaineering in the Sierra Nevada." Boston, 1872. p. 252.

According to various trustworthy authorities, and especially Richthofen,—whose great work, entitled "China," is a treasure-house of information in regard to that country and Central Asia in general,—a vast area, lying between the Kuen-Luen on the south and the Thian-Schan and Altai ranges on the north, has been covered by water until within comparatively recent times. To quote Richthofen's words: "It is a well-established fact, that the ocean, at the end of the Cretaceous period, filled the Han-Hai; that stratified deposits were formed in it, for which the material (sand and gravel) was furnished by the rivers flowing down [from the adjacent mountains]; that this inland sea had a communication with the great ocean, up to an indeterminate later period, through the Djungarian basin or depression [die Dsungarische Mulde]. The Han-Hai is an elongated depression, extending in a west-southwest and east-northeast direction, the western portion of which, where least elevated, near Lake Lop (Lob-Nor) is probably not more than 600 meters above the sea-level, while the deepest depression of the eastern part is 607 meters in elevation. This now dried-up inland sea, the Han-Hai of the Chinese, had—placing its western limit in lon. 75° 30′, and its eastern in lon. 114° 30′—a length of over 1,800 geographical miles, which nearly equals that of the Mediterranean.

"Communication having been cut off between the Han-Hai and the ocean, there was left a great closed basin or inland sea [grosses Binnenmeer], which by gradual evaporation became divided into several smaller basins, and these again gradually diminished in size, some having become quite dry, while others have not yet entirely disappeared, but form salt lakes. The retreat [Rückzug] of this sea may possibly be connected with the period of volcanic activity which has left its traces in the Thian-Schan and in Eastern Mongolia. But nothing is definitely known in regard to the precise time of the formation of this inland sea or its development." *

Richthofen does not, as will be observed, profess to go into any details as to the character and origin of the orographic or climatic phenomena which accompanied, and presumably brought about, this great change in the physical geography of so extensive an area. He cannot, however, avoid noticing that such a succession of events as he describes indicates the prevalence of a dry climate during the later geological periods, for he says: "It may be stated as a certainly ascertained fact, that in Central Asia a dry climate

* China, Vol. I. p. 108.

has prevailed for a long time — as far back as when the Han-Hai was in communication with the great ocean." *

Farther on reference will be again made to some of the points to the consideration of which the desiccation of the Han-Hai naturally leads us. At present we need only allude to the fact that Richthofen evidently considers it as proved that a considerable portion of the diminution of the water-surface of this great inland sea has been accomplished during the historical period, for he says: "The Chinese historical records prove that 4,000 years ago Lob-Nor was an extensive inland sea [ausgedehnter See], and was properly called 'Si-Hai' or Western Lake or Sea." †

Colonel Prjewalsky, the eminent and indefatigable explorer of Central Asia, shows ‡ that Lob-Nor was, at no very remote period, much larger than it now is, and he also states that it is said by the natives to have diminished considerably within the past thirty years. He adds: "Moreover, the fact of a drying-up [Austrocknen] of the lakes is one which is observed all over Central Asia."

Sir T. D. Forsyth, in a portion of his work on East Turkestan § compiled from Dr. Stoliczka's notes, and relating to the geological structure of the mountain ranges between the Tschang-Tschemmo valley and Schahidula on the borders of Kaschgar, thus speaks of the detrital deposits in the valleys of that region: "The melting snow carries large quantities of gravel into the valleys, everywhere forming high benches along the water-courses. During a past epoch, perhaps the diluvial, this process must have taken place on a much larger scale than at present. Not only were the lakes much more extensive, but valleys like the Tschang-Tschemmo and the Tangste were from time to time blocked up by land-slips or glaciers, so that gravel and clay deposits were accumulated, sometimes to a thickness of several hundred feet. Near Aktagh are similar deposits of stratified clay, about 160 feet in thickness, which cover an area of more than a hundred square miles. There can be little doubt that, at the time when these large areas of water existed, the climate of that now cold and dry region was milder and moister than it now is, and also more favorable to animal and vegetable life. Evi-

* China, Vol. I. p. 110. † l. c., p. 125.

‡ Reise an den Lob-Nor, 1876–77. In Ergänzungsheft to Petermann's Mittheilungen, No. 53, p. 21.

§ In Ergänzungsheft to Petermann's Mittheilungen, No. 52, entitled Ost-Turkestan und das Pamir-Plateau, bearbeitet nach dem offiziellen "Report of a Mission to Yarkund in 1873, under command of Sir T. D. Forsyth, K. C. S. I., C. B., Bengal Civil Service." Mr. Forsyth's mission was accompanied by Dr. Stoliczka, as geologist, and it is from his notes that the above-quoted remarks are compiled.

dence of the correctness of this view is to be found in the occurrence of sub-fossil *Succineæ*, *Helices*, and *Pupæ* in the clay deposits of Lake Pangkong, while a land mollusk could, at the present time, hardly exist in that region at all."

That a large part of Siberia has been covered by water up to within quite recent times seems well made out from the accounts given by various geographical explorers within recent years. To cite only one at the present time, Cotta says, in his description of the country between the Ural and the Altai: "The almost horizontal diluvial covering which, without interruption, spreads itself over so enormous an area, that, even when the roads are in good condition, it requires nine days and nights of rapid travelling to get across it, has evidently, at a very recent geological period, been covered by water. We are taught by this fact that Europe, closed in by the Ural, was at that time entirely separated from High Asia, whose northwestern coasts rose precipitously [aufragten] in the Altai, the mountains of Turkestan, and the Caucasus. This water, which formed a division between the two continental masses, was evidently not a great lake, but a broad arm of the sea, which, beginning at the Arctic Ocean with but moderate average depth, was connected with the Mediterranean through the Black Sea, and perhaps even with the Red Sea, across the Isthmus of Suez." *

We have thus shown that High Asia and the countries adjacent to it on the north and northwest have been, within the later geological epochs, the scene of great physical changes, and that the diminution of the water-surface through every portion of this vast area has attracted, in a marked degree, the attention of recent scientific travellers. Without stopping, at the present time, to discuss the statements presented, with reference to the real nature of the phenomenon and its causes, it will be sufficient to call attention to the fact, which cannot fail to have impressed itself on the mind of the reader, that we have to do with an event — or, rather, a series of events — of the utmost importance, if only for the immense size of the area involved in these changes. The analogy between the phenomena presented in High Asia and on its borders and those exhibited in the preceding section, with reference to our own Cordillera region, is most marked, in so far as the existence of a condition of desiccation, during present and past times, is concerned.

Before entering, however, on the proposed general discussion of the subject before us, it will be desirable to present facts of a similar nature to those

* Der Altai. Sein geologischer Bau, und seine Erzlagerstätten. Leipzig, 1871.

already laid before the reader, in reference to other countries. In pursuance of this plan, we may next proceed to consider the region adjacent to the Mediterranean, and especially that which borders this great inland sea on the east and south. And we have to do, in this division of our investigation, with a territory still more interesting, in its connection with the world's history, than that to which our attention has been previously directed. High Asia is looked upon by many as the cradle of the human race; and it is there that recent geological changes might be supposed to have connected themselves most intimately with the history of the intellectual development of mankind. And it is indeed possible that here we might have the most interesting co-ordination of geological and historical events, if only the records of the latter were not so deficient. The migrations of nations from the heart of Asia toward the West are involved in obscurity; and, in fact, all that relates to the earliest history of mankind, throughout the world, is almost an entire blank. That, however, the human race has been the witness of great geological changes can no longer be doubted; but beyond a few of the simplest implements used by man during long ages of his earliest stage of development we have nothing to throw light on his social condition; and in regard to his migrations, through the long lapse of prehistoric ages, we are still more in the dark. That such migrations did take place, however, and on an extensive scale, seems indicated by facts which, although fragmentary and imperfect, are clearly of importance. If such has been the case, then it is reasonable to presume that these wanderings of the prehistoric peoples were largely originated and directed by physical causes. In other words, the movements of the human race have been, and especially in the earlier stages of its existence, from regions presenting less favorable conditions towards those more highly favored in this respect.*

There can be no doubt that if we had an exact account of all that has transpired on the borders of High Asia since the human race began its existence in those regions, it would be equivalent to having a flood of light thrown upon what is now almost totally in obscurity, namely, the intellectual development of man as affected by external physical conditions. At present the countries adjacent to the Mediterranean present the most favorable field for investigations of this kind, because here the historical records are most complete. Not only are they the most complete, but they

* "The progress of human generations is shaped by the physical circumstances in which they live." J. W. Draper, in "Thoughts on the Future Civil Policy of America." New York, 1865, p. 66.

go farthest back in point of absolute time;* and when written records begin to fail, architectural monuments, to some extent, supply the deficiency. So extensive is the subject at present before us, that it is not possible to do more than throw out a few hints as to conclusions reached, not without considerable examination of authorities on the part of the present writer; so that, if the body of evidence seems small, in comparison with the magnitude of the conclusions drawn, it is rather from want of space in which to dilate, than from defect of material.

That most of that which we recognize as forming the basis of our intellectual culture, science, art, literature, and religion has come to us from countries bordering on the Mediterranean, no one will deny. How far, exactly, Egyptian, Greek, and Arabian authorities have been dependent on and drawn from each other will perhaps never be accurately known; nor is it material that it should be, from the point of view of the present inquiry. We know that, either successively or by turns, these nations at the east end of the Mediterranean shone with a brilliant light on what to us seems to have been the outer darkness of the rest of the world. We know that from the eastern end of that great inland sea light, perhaps with sundry vibrations back and forth, reached the central portion, and later the western end. Egypt, Greece, Asia Minor, Arabia, Italy, the southern shore of the Mediterranean west of Italy, and Spain, have each, in turn, ruled the world, either by intellect or by force, or more often by the inevitable combination of the two. That no one of these countries stands in any such relation to the rest of the world, at the present time, will be readily admitted; and more than this may be affirmed with truth. As a rule, these nations have reached a stage of decadence from which they can never rise to occupy again the position which they have lost. The Egyptian fellah and the Arabian bedouin know nothing of the glorious history of their predecessors on the soil they now occupy, and from whom they are lineally descended. Modern civilization, the direct outcome of that which their ancestors originated and handed over to the comparatively barbaric races of the North and West, has gone utterly beyond their ken, and is something to which they can never find their way again.

That the statement here made would be found to be strictly true in all its

* There may be an exception to this in the case of the historical records of the Chinese people; but the language, style of thought, and general development of that nation are so foreign to our own, and have had so little influence on us, that — for the present at least — that country can hardly be taken into consideration in connection with an inquiry of the kind suggested above.

details, if examined with a critical eye, is not intended to be maintained. The countries on the north side of the Mediterranean, for instance, although no longer able to dominate the civilized world, are not without some participation in its intellectual progress. Italy and Spain have kept pace to a considerable extent with modern civilization, neither of these countries exhibiting that stage of decadence which Greece does; while the latter country is far in advance of the region to the south and east.

The reasons for the mighty changes which have taken place in successive ages among the nations which have had to do with the intellectual development of the world and the spread of civilization are usually sought for in something connected with an inherent property of decay belonging to the various races, or to the human race in general — something not dependent on the physical conditions by which the races in question have come to be surrounded as the ages rolled by. When, however, we observe, that not only in those regions of High Asia from which migrations are usually supposed to have begun, but all through the countries bordering on the Mediterranean, we are everywhere confronted by evidences of a change of climate, and the entering in of conditions evidently unfavorable to mental vigor and national welfare, we are justified, as the writer believes, in asking the questions, Is it not in consequence of these changes in the physical conditions that the races themselves have changed, and has not the climate of a considerable portion of the region in question become such that we can say with truth that it is incompatible with a maintenance of those modes and habits of life which accompany high civilization?

The evidences of a diminution of the amount of water standing and flowing upon the surface in the various countries bordering on the Mediterranean, especially those on the east and south, are most ample and of varied character. But it is especially the conformation of the surface which leads us to infer a most decided desiccation during the latest geological periods. There are everywhere not only depressions which have all the appearance of once having been occupied by lakes, as evidenced by the terrace-marks and other indications of the former presence of water, but there are also numerous long, continuous valleys, — *cañons*, as they would be called in California, — which show by their form and position that they can only have been formed by running streams; and these valleys are now, almost without exception, either entirely dry the whole year round, or only occupied by water here and there at very irregular intervals of time.

As has been done in the preceding pages for Central Asia, so here only a few references can be made to the writings of scientific travellers who have made mention of facts bearing on the question before us; and, in preference, the most recent authorities will usually be cited.

Arabia may be first mentioned, as a striking instance of a country greatly diminished in population, and utterly cast down from the high position it once held; while, at the same time, it presents ample evidences of a great climatic change during the most recent periods.

Vivien de Saint-Martin says of this country: "There can be no doubt that, since the days of antiquity [les temps antiques] the climate and the physical conditions of a part of Arabia have undergone very great changes, in consequence of the disappearance of the forests on the western coast mountains. M. Fulgence Fresnel, an excellent observer, wrote in 1837 as follows: 'It is a well established fact that the volume of flowing water is constantly diminishing [diminue sans cesse], and has not ceased to diminish, in a country celebrated for its dryness even in the days of Abraham, in a country where Ishmael owed to a miraculous interposition the existence of the spring which saved his life. People still remember that, in the valley of Sapra, there was a time when there was running water in the Bouraikah; but that stream has now dried up, and Djar, indicated on Niebuhr's map, belongs to ancient geography.' " *

Noel des Vergers, in his "Description de l'Arabie," says: "Unfortunately the return of the rainy season, which hardly suffices for a few torrents, and is not enough to keep a single stream alive during the whole year, is liable to distressing interruptions. An absolute drought sometimes lasts for two or three years continuously over a portion of some province, rendering the whole region barren, and producing famine and all the accompanying diseases." †

Lady Anne Blunt says: "The whole of the peninsula, with the exception perhaps of Yemen and certain districts of Hadramaut within the influence of the monsoon winds, is a rainless, waterless region, in every sense of the word a desert. The soil is a poor one, mainly of gravel or of sand, and, except in a few favored spots, unsuited for cultivation; indeed, no cultivation is possible at all in Nejd, except with the help of irrigation, and, as there is no water above ground, of irrigation from wells. Even wells are

* Nouveau Dictionnaire de Géographie Universelle. Paris, 1877. Article "Arabie."

† Quoted by Vivien de Saint-Martin, l. c., Vol. I. p. 74.

rare. The general character of the central plateaus, and of the peninsula, is that of vast uplands of gravel, as nearly destitute of vegetation as any in the world, and incapable of retaining water, even at a great depth. It is only in certain depressions of the plain, several hundred feet lower than the general level, that wells as a rule are found, and wherever this occurs with a sufficient supply of water, towns and villages, with gardens round them, have sprung up. These, however, are often widely apart, showing in mere spots on the map of Arabia, and unconnected with each other by any intervening spots of agricultural land." *

Mr. Blunt, in his "Notes on the Physical Geography of Northern Arabia," appended to Lady Anne Blunt's book, speaks repeatedly of the depressions in the desert, as having once been filled with water. For instance, in his description of the Wady Sirhan he says: "In the days when it was an inland sea, it must have received contributions from all sides." † Farther on, in speaking of the same Wady, he remarks as follows: "It is probable that in the days when Arabia was more populous than now, villages existed in it at intervals from Ezrak to Jôf. At present, the wells of these only remain, if we except the twin oases of Kâf and Ithery, still preserved in life by the salt lakes which supply them with an article of trade. These are but poor places, and their population can hardly exceed 200 souls."

It will not be necessary to make farther citations in regard to the desiccation of Arabia; that the population of that country has greatly diminished, seems evident; but since the actual population is not known with even an approximation to accuracy, no statistics can be given. ‡

For the region north of Arabia, including Asia Minor, Syria, and Mesopotamia, facts of the kind stated above in reference to Arabia and Persia are everywhere presented to the investigation of the traveller. A few only of those lately published need be quoted. In a "Memorandum on the Euphrates Valley Railway," Mr. W. Blunt — to whom reference has already been made — notices repeatedly the depopulation of the region traversed by that river. He remarks as follows: "I think it more than probable that in the day of Babylonian greatness the flooding of both rivers [the Tigris and Euphrates] was more regular, and less subject to disasters of drouth and

* A Pilgrimage to Nejd. By Lady Anne Blunt. London, 1881. Vol. I. p. 258.

† l. c., Vol. II. p. 237.

‡ For some time 12,000,000 was given, in the geographical text-books, as the population of Arabia; this number was, in 1859, suddenly reduced by the best authorities to "about 5,000,000." (See Behm's geographisches Jahrbuch, Band I. 1866, p. 59.) Even this number may be considerably too high.

excess than now. As I have said, the denudation of Armenia accounts perhaps for the destruction of Irak. In any case it is certain, that at the present moment the full energies of the existing population are required to preserve their footing, not to make new conquests on the river. Now, as I am writing, Lower Mesopotamia is expecting famine from the failure of the Tigris, for not an acre of wheat can be sown without its flooding." *

The following is quoted from Dr. C. Fraas: "The most fruitful land of antiquity was, as is well known, the region bordering on the Lower Euphrates and Tigris, and particularly that called in later times Mesopotamia. As the sacred writings of the Hebrews have assigned this as the country from which the founder of their religion emigrated, it is an attractive subject to compare its former with its present fruitfulness. As Richter says, the land of great canals is now desert and barren, without settlements, and a dried-up wilderness. The once most fertile alluvial bottoms, intersected by numerous lines of canals and ditches, are now covered with a growth of the plants peculiar to a saline soil, and all this where once was the 'garden of the world.'" †

Professor E. H. Palmer gives a number of quotations from the Jewish sacred books, which, he says, "tend to confirm the supposition that the Peninsula [of Sinai] was better supplied with water at the time of the Exodus." ‡ He considers it certain that there was, at that time, a large population in and near Sinai; and among them were colonies of Egyptian miners, "whose slag-heaps and furnaces are to be seen in every part of the Peninsula. These must have destroyed many miles of forest in order to procure the fuel necessary for carrying on their operations; nay more, the children of Israel could not have passed through without consuming vast quantities of fuel too. But if forest after forest disappeared in this way, if population dwindled down to a few non-agricultural tribes, and cultivation were neglected, then the rain that falls so seldom would no longer stay to fertilize the land, but in an unimpeded torrent would find its way to the sea; a burning summer sun would soon complete the work, and a few ages would make the Peninsula of Sinai what we see it now."

Captain Burton says: "That great changes for the worse have taken place in the Sinaitic Peninsula, and in the Négeb, or South Country, we know from

* A Pilgrimage to Nejd, Vol. II. p. 276.

† Klima und Pflanzenwelt in der Zeit, ein Beitrag zur Geschichte beider, von C. Fraas. Landshut, 1847, p. 20.

‡ The Desert of the Exodus. 2 vols. London, Vol. I. p. 25.

the expeditions of Messrs. Tyrwhitt-Drake and Palmer, who found undoubted traces of rich pasturages of watered ground and of human habitation, where all is now a howling waste." * Farther on, the same author remarks: "The once wealthy and commercial land of Midian, now 'destitute of that whereof it was once full,' has become a desolation among the nations. The cities and goodly castles of the sea-board are ruinous heaps, almost level with the ground. 'The Desert has resumed its rights; the intrusive hand of cultivation has been driven back; the race that dwelt here have perished; and their works now look abroad in loneliness over the mighty waste.' The interior, formerly so rich in oases if not in smiling field and pasture-land, has been disforested to a howling wilderness; and the area of some three thousand square miles, which, thirty-one centuries ago, could send into the field 135,000 swordsmen, is abandoned to a few hundreds of a mongrel Egypto-Bedawi race, half peasants, half nomads, whose only objects in life are to plunder, maim and murder one another." †

Of the very large amount of matter which could be laid before the reader proving, beyond the possibility of doubt, that the climate of the region bordering the Mediterranean on the south has undergone a marked change in later geological times, and that this has been continued into the historical period, only a small portion will be presented. As has already been made apparent from the tenor of some of the quotations offered, the almost universal belief is, that the indicated change of climate has been chiefly brought about by the disforesting of the country, or perhaps also in part by long-continued cultivation. All, however, that is intended, in the present section, is to show that a change from prosperity to stagnation, from fertility to barrenness, and from favorable climatic conditions to utter dryness, has affected the whole area in question. Of the cause of this, the discussion will follow farther on.

The first quotation is from the work of C. Fraas, already cited, and it relates to the proofs of a change of climate in Egypt during historical as well as prehistoric times. This author thus expresses himself: "As we have already repeatedly had occasion to notice what great revolutions have been brought about by changes of climate, we shall find no difficulty in proving this in regard to a country which has been so long inhabited as Egypt. Long before our time attention was called to these changes by

* The Gold Mines of Midian and the Ruined Midianite Cities. 2d ed. London, 1878, p. 290.

† l. c., p. 391.

Russegger, who recognized in the deep gorges of the desert mountains, in the deep Ghors, or torrential stream-beds of tropical Africa, the results of long-continued and heavy rains in former ages. Certainly, at the time when the country was at the height of its prosperity, when it was traversed by numerous canals, when artificial lakes, such especially as Lake Mœris, covered it, when cultivation extended far beyond the present boundaries of the desert — when all this was the case, certainly the climate must have been very different from what it now is. What mean all those petrified remains of various kinds of trees which are so frequently found in Egypt? The tradition that Lower Egypt at least was once an arm of the sea? The once larger area of alluvial plain, and the very much larger water-surfaces exposed to evaporation? The plants, finally, in regard to which we intend to give more details farther on, and of which plants some, like the Nelumbo, require a very moist soil, and which, formerly the principal article of diet, has now entirely disappeared from Egypt?"*

Fraas, after a brief discussion of Russegger's ideas in regard to the causes of the desiccation in question, to which we shall have occasion to revert farther on, proceeds to give numerous instances of changes in the distribution of plants, especially of cultivated ones; which changes have taken place in later geological times, and which seem to him to prove a marked decrease in the amount of moisture.

Mr. Andrew L. Adams, in his account of an examination of the so-called petrified forest of the Mogattam Hills, writes as follows: "This silicified wood deposit appears to belong to a more recent epoch than the nummulitic rocks, and may be referable to a period immediately preceding the submergence of the Sahara and general depression of North Africa just noticed; or, in other words, contemporaneous with the age when the river flowed over the plateaus of Nubia. No traces of ancient levels or terraces were observed, but about Beni Hassan we could define terraced cliffs on the sides of the long straight glens, also ravines and larger valleys, which may in part have been formed by the denuding influence of the sea, during the oscillations of level, and since farther opened out by atmospheric agencies. No doubt more extended observations would elicit important data in connexion with this interesting subject. Who can tell how far the Egyptian priests erred when they informed Herodotus that at the time when Menes, the first mortal, reigned over Egypt 'all the country except the district of Thebes was a

* Klima und Pflanzenwelt, p. 41.

morass, and that no part of the land that now exists below Lake Myris was then above water'?"*

Mr. Adams, farther on, remarks, in reference to the constant encroachment of the desert sands on the arable lands of Egypt: "Already many arable plains are covered over; indeed the gradual desertion of entire villages, and the partial evacuation of others, are just in proportion to the steady encroachment of the desert. The struggle between man and nature is here remarkable, for, should the present order of things be continued, it must finally eventuate in a complete victory to the latter whenever the odds are favorable." †

Professor Unger, in his interesting work describing his scientific journeys in Greece,‡ has a chapter headed, "Is the Orient capable, so far as its physical nature is concerned, of regeneration?" ["Ist der Orient, von Seite seiner physischen Natur, einer Wiedergeburt fähig?"] The views which the author sets forth in this chapter, in reference to changes of climate in the vicinity of the Mediterranean, will be noticed farther on; at present, only one quotation will be made, for the purpose of introducing the views of Fallmerayer, an eminent Oriental traveller and historian whom Unger thus cites: "As to what especially relates to Greece, Fallmerayer has already called attention to the fact that, together with an entire change in the races inhabiting ancient Hellas, its capacity for production has changed with the climatic conditions; that, instead of the former fruitful and well watered meadows and pastures, now only dry fields and bosky hills devoid of forests are to be found, and that, in consequence of this, it is impossible that Greece should ever be again drawn within the circle of Western culture. Fraas has brought forward the same idea, and supported it by additional proofs." § It may be added that Fraas extends these views so as to embrace the whole region adjacent to the "lands of the ancient home of culture," including Persia, Asia Minor, Syria, Greece, and Egypt.

Professor O. Fraas,|| in his investigations of the physical geography of

* In Notes of a Naturalist in the Nile Valley and Malta. Edinburgh, 1870, p. 66.

† l. c., p. 70.

‡ Dr. Fr. Unger: Wissenschaftliche Ergebnisse einer Reise in Griechenland und in den Ionischen Inseln. Wien, 1862, p. 188.

§ See, Gesammelte Werke von Jakob Philipp Fallmerayer. 3 vols. Leipzig, 1861, Vol. II. p. 468; also the preface to Geschichte der Halbinsel Morea, während des Mittelalters, by the same. 2 vols. Stuttgart, 1830.

|| Dr. C. Fraas, "Inspector und Lehrer der Chemie und Technologie an der königl. Centrallandwirthschafts-Schule zu Schleissheim," is not to be confounded with Dr. Oscar Fraas, "Conservator an der königl. Naturalien-Cabinet zu Stuttgart."

the countries bordering on the Mediterranean, gives his attention especially to the increasing dryness of that region, referring repeatedly to the proofs of a change of climate in those countries during the historic period. Of the many quotations, in point, which might be made from his work,* the following is selected: "What a difference between this idea of life [Lebensanschauung], held in ancient Egypt, taken from the City of the Dead of Saqára and the pyramids, and the idea of life drawn from the royal graves of Qúrna and Medinet Habu. It is hardly possible to say which required the longer time, the changes of popular belief [Volksglaube] or the introduction and dissemination of new domestic animals. The camel is still wanting even on the walls of the temples of Thebes, and had certainly not been introduced at the time of the founding of that city, for there was no desert then. Magnificent buildings, such as those in the Assassi Mountain, or in Denderah, and the giant structures of the world, on which we gaze, at the present time, with the deepest feeling of our own insignificance [Armseligkeit] — such buildings were not placed away to one side in the desert, where they could only be reached with difficulty and danger. Thousands of walls were not covered, from floor to roof, with inscriptions, paintings, and sculptures, that they might remain unseen in the night of the grave; but that the writing might be read, and the works of art inspected. The remains of both the most ancient, and the ancient, Egypt speak as loudly of the changed climate of the Nile-lands as do the gravels [Gerölle] in the Wadys of the Libyan desert of former floods of water, where now, year out and year in, no drop of water ever flows. . . . . An intellectual activity like that of the times of the Greeks, when Alexandria was the centre of all the arts and sciences, a true world's university, with the richest library on earth; or as that which existed from the times of the Platonists up to the first centuries of the Christian era, when the greatest thinkers of the church — such as the Gnostic Origen — developed their philosophical-religious systems, — such a movement of thought demands, as an absolute necessity, a different climate, and a moister air, than that now prevailing in Egypt. On the present soil of the Nile-land never again will any philosophical system be developed; and no power in the world could cause an University to arise there which should have even the most distant resemblance to an European one."

* Aus dem Orient: Geologische Beobachtungen am Nil, auf der Sinai-Halbinsel, und in Syrien. Stuttgart, 1867.

From the above quotation it will be easily made out that Fraas considers that there is no avoiding the conclusion that the Mediterranean region — the eastern portion of it, at least — has undergone a most decided climatic change, not only in later geological times, but within the past 2,000 years.

Professor Zittel, when speaking of one of the oases of the Libyan desert, — that of Chargeh, — says: "In many places there are to be seen in this oasis, where now all is sterile, old ruins of sacred and profane buildings, traces of fields formerly under cultivation, wells which have caved in; — in short, a host of proofs of a former much larger population of this region." * Professor Zittel takes, however, a much less disparaging view of the condition of things in this portion of Egypt than does Dr. Fraas, since the former believes it not impossible that, *if Artesian wells could be successfully bored*, the Libyan desert might return to its former condition of prosperity. That condition, however, if we may judge from the character and habits of the population of that portion of the Sahara where such wells have, to a certain limited extent, succeeded, would have but a very slight resemblance to what we are now accustomed to consider as civilization. Wandering tribes living almost exclusively on the fruit of the date-palm, such as they are described by Desor † and others, have little in common with the dwellers in countries better supplied with water. Nor is any instance to be found on the face of the earth of a people living in prosperity and yet dependent exclusively on Artesian water. Indeed, as appears clear to the present writer, the Artesian wells of the Libyan desert have not run dry because the country has been abandoned; but the case is exactly the opposite of this, — the water having given out, life is no longer possible except under conditions in the highest degree unfavorable to prosperity.

In regard to the extensive area to the west of Egypt, including Tunis, Algiers, and the vast region of the Sahara, we have an abundance of observations, made within the most recent period, by eminent observers, all tending to prove, almost beyond possibility of doubt, that conditions similar to those described as existing farther east, along the Mediterranean, and beyond it through Central Asia, prevail here, and on quite as extensive a scale. As in the Libyan desert, and in Syria and Arabia, the whole aspect of the surface is that of a region at no very distant time in the past quite abundantly watered, but now given over, in large part, to almost hopeless

* Briefe aus der Libyschen Wüste. München, 1875.

† Aus Sahara und Atlas.

sterility. As on the eastern borders of the Mediterranean, so farther west, there are abundant evidences of the former presence of nations possessing a much higher grade of civilization than that of the present population, whose numbers have dwindled with their diminishing intelligence, and whose habits and modes of life, while eminently suited to the physical conditions by which they are surrounded, are beyond a doubt incompatible with what is now called civilization. Everywhere the ruins of former greatness are to be seen, offering a striking contrast to the present struggle for mere existence necessitated by the diminished area susceptible of cultivation, and the impossibility of procuring a sufficient supply of water for irrigation, except in a few favored localities, of exceedingly small dimensions as compared with the extent of the surrounding desert.

The recent explorations of the Sahara have resulted in the correction of some of the former erroneous impressions prevailing in regard to the real causes of the increased dryness of that region. The examinations made by Desor of a limited area, on the northern edge of that part of Africa known as the Desert of Sahara, led him to form the idea — which, for a time, was very generally adopted — that the whole of this vast region had formerly been covered by the sea, and that it had been raised above water during the very latest portion of the Tertiary epoch. This elevation of the land, according to Desor, brought about not only the dryness of the Sahara itself, but had a powerful influence in putting an end to the phenomena of the glacial epoch, as will be mentioned farther on.

It is now known, however, that only a small part of the Sahara has been covered by the sea at any period since the Cretaceous epoch. On the contrary, we find everywhere abundant proof of the former presence of fresh water, which stood in lakes or ran in rivers; and, of course, a corresponding amount of evidence that there has been a marked change of climate during recent periods. In fact, there seems to be little doubt that this change, whenever begun, has been continued during the historic period, the kind of evidence furnished by recent investigators being precisely similar in character to that already brought forward in reference to Syria, Egypt, and the Libyan desert. The remains of buildings of various dates, as well as the records of history, show conclusively that large portions of Northern Africa were once much more thickly populated than they now are; but that the stage of civilization then reached was far higher than that of the present inhabitants, whose mode of life is strictly in accordance with the conditions imposed on them by the desert nature of a country where only an occasional oasis can, by artificial irrigation, be made to bear fruit enough to give a scanty support to a limited population.

Dr. Chavanne has, so to speak, monographed the Sahara,* and given a very complete *résumé* of all that has been found out about that region up to a very recent date. His views, which appear to the present writer to be, in the main, justified by the facts, may be inferred from the following quotations: "Up to the most recent period, it was generally thought to be a fact which could not be controverted, that the Sahara had been, during the most recent geological period, one great inland sea, and that, consequently, the dunes, or accumulations of sand of the present sea of that material, which cover the region, were the relics of that sea. The existence of numerous schotts, sebchas and salt morasses, the discovery of brackish-water shells (*Cardium edule*) in the northern part of the Sahara, at an elevation of from 200 to 300 meters, seemed to prove the truth of this theory beyond possibility of dispute. The well-known German geologists, Desor and Escher von der Linth, who in 1863, in company with Professor Martins, of Montpellier, made a journey to the Algerian Sahara, published results of their observations which appeared to confirm the hypothesis in question; and Desor carried the theory still farther, inasmuch as he endeavored to show that the Sahara was the grand regulator of the climate of South and Middle Europe, and to connect the extension of the Alpine glaciers with the former watery covering of Northern Africa. However enticing [verlockend] this theory may be, it is not supported by the facts. The first impression which the traveller gets of the desert, especially when standing on the southern slope of the mountains bordering the Sahara on the north, is indeed highly favorable to the hypothesis of a former occupation of this region by the sea. The writer himself, when visiting the northern edge of the desert, was led to look on this theory as most probably correct. An exhaustive and unprejudiced examination of the mode of formation of the sand accumulations, the consideration of indisputable facts, such as the existence of crocodiles in the heart of the Sahara, and of petrified forests in the Libyan oases, cannot but lead to the conclusion that the present sandy regions owe their existence to some other cause than that of a former universal water covering. Humboldt long ago recognized the influence of general geographical

* In his volume entitled "Die Sahara, oder von Oase zu Oase." Wien, 1879. See also another later work, by the same author, "Afrika im Lichte unserer Tage." Wien, 1881.

position on the formation of desert regions; and later investigations, like those of Duveyrier, Dr. Marés, and Vatonne, made on the spot, in regard to the formation of sand dunes, as well as those of Hann and Wojeikoff on the influence of meteorological conditions on the desert surface, render the conception of the desert as the product of climato-meteorological changes more and more probable. It is not intended, however, by this, to assert that, during the latest geological period, numerous larger and smaller inland lakes may not have existed in the Sahara; on the contrary, we are obliged to recognize the numerous sebchas and dayas as the remains of such fresh- or brackish-water collections. In the Western Sahara, at all events, these lakes did not have any great extension during the Quaternary epoch, and they were separated by the previously mentioned range of elevations from the great inland sea, which occupied the place of the present sea of sand of the Libyan Desert. The correctness of this view appears to be fully confirmed, by the fact that, up to the present time, no marine deposits or fossils have been found in the western basin, while such are by no means wanting in the Libyan Desert.

"In the present distribution of certain animals we find strong reasons for believing that, even in historical times, the Sahara was less extensive and less of a desert than it now is. First; the late introduction of the camel, which was not domesticated in Northern Africa until one or two centuries after the birth of Christ. Again; there must have been in the Southern Atlas, in ancient times, numerous wild elephants, since we know that the Carthaginians caught their war-elephants within their own territory. So, too, the hippopotamus existed in a region where now it could not, by any means, find sufficient water, the same being the case with the elephant as respects food. Crocodiles, which in former times occurred in prodigious numbers, were also supposed to have died out; but, not long since, a French traveller, Baron Aucapitaine, found some still living in the Wadi-el-Dscheddi; and, still more recently, Edwin von Bary proved their existence in the uninhabited valley of Mihero, on the Tasili plateau. The former occurrence of all these animals in the Northern Sahara, which in its present condition would present an insurmountable barrier to their introduction from the South, renders the adoption of the hypothesis of a former more luxuriant vegetation and more abundant precipitation where now there is only desert, a matter almost of absolute necessity. In general it may be said that, south of the 34th parallel, in this region, there has been a constant advance of the desert since the historic period [seit dem Alterthume die Wüstenbildung ohne Unterbrechung im Fortschreiten begriffen ist]."

Farther on, Chavanne remarks as follows: "That, however, the quantity of water [der Wasserschatz] in the Sahara has diminished, and that this region has become drier since the days of historical antiquity, can now be no longer doubted." *

The evidence of a great climatic change in Northern Africa, and generally in the countries bordering the Mediterranean, is so clear, that it is not necessary to dwell longer upon this region. As to the central and southern portions of that continent, it is not to be expected that such an array of facts as has been presented with regard to Egypt and the Sahara could be brought forward, even if desiccation had proceeded all over Africa with the same rapidity as on its northern borders. In the first place, the central portion of that continent is quite differently situated from the northern area with reference to those meteorological conditions influencing precipitation, so that the larger part of it is superabundantly supplied with moisture, at least during a certain season of the year. And a diminution of an abundant supply to one less abundant, but still ample for the wants of animal and vegetable life, is not, by any means, a phenomenon of the same character as that of a falling-off from moderate to very small, although, in reality, the actual decrease may be as great in one case as in the other. It is only when the decrease of precipitation has reached that point where its effects begin to be marked in making life difficult, that much heed would be likely to be paid to it.

But, again, Central Africa is a region which is inhabited by uncivilized races, and of which the scientific exploration has but just begun, the principal geographical facts concerning it being, as yet, hardly made out in outline. Moreover, it has no recorded history, other than that offered by nature herself; while data furnished by trained geological observers are entirely wanting, at least for much the larger portion of the country. The existence of numerous lakes, many of which are of great size, so that the whole region is one of the most remarkable, in respect to the importance of its lacustrine areas, of any on the globe, is, however, now a well-ascertained fact, and evidence that these lakes have been diminishing in size during recent times is by no means wanting. Indeed, that most remarkable traveller, Livingstone, seems, at an early period of his investigations in Africa,

* l. c., p. 627.

to have been profoundly impressed with the appearances which presented themselves in various localities of a former much greater expansion of the lake system, both of Central and Southern Central Africa, as the following quotations from his principal volume prove: ". . . . consequently, when the river [Lekone] flowed along this ancient bed, instead of through the rent, the whole country between this, and the ridge beyond Libebe westwards; Lake Ngami and the Zouga southwards; and eastwards beyond Nchokotsa, was one large fresh-water lake. There is abundant evidence of the existence and extent of this vast lake in the longitudes indicated, and stretching from 17° to 21° S. latitude. . . . . All the African lakes hitherto discovered are shallow, in consequence of being the mere *residua* of very much larger ancient bodies of water. There can be no doubt that this continent was, in former times, very much more copiously supplied with water than at present, but a natural process of drainage has been going on for ages. . . . . Whether this process of desiccation is as rapid throughout the continent, as in a letter to the late Dean Buckland, in 1843, I showed to have been the case in the Bechuana country, it is not for me to say." *

Livingstone's ideas in regard to the diminution of some of these lakes and the disappearance of others need not here be dwelt upon. Naturally, they are highly catastrophic in character, the idea of a possible diminution of the rain-fall not having occurred to him, although the facts which he furnishes seem very clearly to point in that direction, rather than towards drainage by earthquake fissures and the like events.

The entire aspect of Southern Africa, as described by recent travellers, is that of a region which has undergone great changes of climate within a recent period. Dryness is pre-eminently its characteristic at the present time; but in the whole appearance of the country there is proof—as it appears to the writer—that this dryness has been on the increase since the southern part of the continent acquired its present topography. There has certainly been a great diminution of the water-surface since the Tertiary epoch began.

A considerable portion of Europe belongs in the same category as North-eastern North America in its relations to the question now before us. The phenomena of desiccation are complicated with those of former glaciation, so that it is not so easy to separate the two classes of facts from each other;

* Missionary Travels in South Africa. London, 1857, Chapter XXVI., under the heading of "Ancient Lakes."

hence the special considerations of the decrease of moisture in formerly glaciated regions will be deferred for the present. A few remarks will, however, be made, at this point, in reference to an interesting fact, namely, the decrease of the volume of the rivers of Central Europe during the later historic times.

In some portions of Germany records have been kept for many years of the flow of water in some of the principal rivers, and the question naturally suggested itself, whether a comparison of these records would show that the volume of water passing from year to year, at various points, had diminished or increased, or on the other hand remained constant. The eminent geographer, Berghaus, was one of the first to take up this investigation. He worked up the observations of the Rhine made at Emmerich, those of the Elbe at Magdeburg, and those of the Oder at Küstrin, and came to the conclusion that each of these rivers had diminished in volume during the past hundred years, and that there was reason to fear that they would eventually disappear from the list of the navigable streams of Germany.

Later than this, an eminent hydraulic engineer, Gustav Wex, Chief Director of the Donauregulirung, — an important work undertaken with a view to the regulation and improvement of the channel of the Danube at and near Vienna, — entered upon the same investigation, and in much greater detail. His results, however, are similar in character to those of Berghaus, and seem to demonstrate, beyond possibility of doubt, that the principal streams of Middle Europe, namely, the Danube, the Rhine, the Elbe, the Vistula, and the Oder, together draining an area of 570,000 square miles, have for many years been carrying a constantly diminishing quantity of water. The longest series used in coming to this conclusion is that of the Elbe at Magdeburg, where the records go back for one hundred and forty-two years; but the observations for shorter periods of from fifty to seventy years, which in the case of the other streams are all that are available, seem to leave no doubt as to the character of the result.*

We turn, finally, for evidence of desiccation to the southern counterpart of our own continental mass. Striking as is, in many respects, the resemblance in orographic structure between North and South America, there is one point in regard to which the difference is very marked. The Cordilleras of North America form a complex of ranges which occupy a very considerable width, not less than a thousand miles in their widest portion, while the

* See Zeitschrift des öst. Ingenieur und Architekten Vereins, for 1873.

Andes of South America are much narrower, a section east and west across them hardly averaging more than a third in length of that of a similar line across the North American Cordilleras. Of course, under such conditions, it is to be expected that the closed-basin region of South America, if one existed at all, would be much less extensive than our own. This is, in reality, the fact, the drainage of a large part of the interior portions of the Andes being very completely effected by the branches of the great rivers which traverse the ranges by means of immense transverse breaks across them.

Another important fact to be taken into consideration in this connection is this: that the wide part of South America lies wholly in the tropical regions, and is therefore subject to a very different *régime* from that of an area within the temperate zone, like our own Cordilleras. The rain-fall of the South American continent is very peculiarly affected, however, by the position of the mountain ranges with reference to the trade-winds. Closed-basin areas do exist in the Andes, and here, as we might have expected, from analogy with the facts already described from our own western regions, there are also clear evidences of desiccation in recent geological times.

The closed basin occupied in part by Lake Titicaca is the most important area of this kind in the Andes, and from the description furnished by A. Agassiz* it is possible to state as an unquestionable fact, that the area of water-surface not only of this lake, but of the region generally, has greatly diminished in later times. The following quotation is offered in support of this statement.

"Lake Titicaca must have, within a comparatively very recent geological period, formed quite an inland sea. The terraces of its former shores are everywhere most distinctly to be traced, showing that its water-level must have had an elevation of 300 or 400 feet at least higher than its present level. This alone would send its shores far to the north in the direction of Pucara, forming a narrow arm reaching up to S. Rosa. Lake Arapa is probably only an outlier of the ancient lake, as well as several of the small lakes, now at a considerable distance from the west shore. The immense plain of Cabanillas, extending north beyond Lampa to Juliaca, only 100 or 120 feet above the lake at its highest point, was one sheet of water. The terraces of the former shores are still very distinctly to be seen. . . . . The plains, now laid bare at the northern and western shores of Lake Titicaca, give us an excellent idea the appearance the whole basin of the lake would present if

* Hydrographic Sketch of Lake Titicaca; Proc. Am. Acad., Vol. XI. 1876, p. 288.

entirely dry. The number of lakes and basins, great and small, which formerly covered the elevated plateau of the Andes, must have been very great; but we now find only here and there a small sheet of water. The former lakes are only represented by the more or less extensive pampas, forming basins at great altitudes, showing plainly that the whole of this district is receiving a much smaller waterfall than in former times, but probably not in historic times, if we take into consideration the position of some of the most ancient ruins of Bolivia (at Tiahuanaco), which are only about seventy-five feet above the present level of the lake."

The diminution of the water, shown by Mr. Agassiz to be so positively proved for the region embraced within the field of his explorations, did not escape the notice of Humboldt; on the contrary, he repeatedly calls attention to the fact of a general desiccation in those parts of South America which he visited, and he comments, somewhat at length, on the cause of the phenomenon. The decrease in size of the Lake of Valencia, near Caraccas, especially interested him, as will be evident from the following quotation: "But it is not alone the picturesque beauties of the Lake of Valencia that have given celebrity to its banks. This basin presents several other phenomena, and suggests questions, the solution of which is interesting alike to science and to the well-being of the inhabitants. What are the causes of the diminution of the waters of the lake? Is this diminution more rapid now than in former ages? . . . . I have no doubt that, in very remote times, the whole valley, from the foot of the mountains of Cocuyza to those of Torito and Nirgua, and from La Sierra de Mariara to the chain of Guigue, of Guacimo, and La Palma, was filled with water. . . . . Within half a century, and particularly within these thirty years, the natural desiccation of this great basin has excited general attention. We find vast tracts of land which were formerly inundated, now dry, and already cultivated with plantains, sugar-canes, or cotton. Wherever a hut is erected on the bank of the lake, we see the shore receding from year to year. We discover islands, which, in consequence of the retreat of the waters, are just beginning to be joined to the continent, as for instance the rocky island of Culebra, in the direction of Guigue; other islands already form promontories, as the Morro, between Guigue and Nueva Valencia, and La Cabrera, southeast of Mariara; others again are now rising in the islands themselves like scattered hills." *

Humboldt continues, at length, with the narration of similar facts, proving

* Personal Narrative of Travels to the Equinoctial Regions of America. Bohn's Ed. in 3 vols. Vol. II. p. 4.

desiccation in this portion of South America, and enters into a discussion as to the causes of the phenomenon, to which we shall have occasion to revert farther on.

It seems unnecessary to multiply evidence of the kind given in the preceding pages. The fact cannot fail to have impressed the reader that, however striking the phenomena of desiccation may have been shown to be in our own western region, they are not less so in the Old World; where we have an additional interest imparted to the investigation, by the fact that we have here to do with the historically important portion of the world, so that the connection of the desiccation with the growth, migrations, and decay of civilized nations makes it a matter of the utmost importance. In the course of the next chapter additional information will be, of necessity, introduced, in regard to the phenomena which have occupied us during the present one. Having shown the fact of a desiccation going on at least during the later geological periods, and continuing up to the present day, certainly over a large part of both hemispheres, in both the Old and New Worlds, we are now prepared to proceed with the discussion of the facts presented, and to endeavor to ascertain what cause or causes have been influential in bringing about the condition of things described. That the problem is a complicated and difficult one will not be denied; but it is hoped that, in the following chapter, some light will be thrown upon it, even if there are questions raised to which it is not easy to give an entirely satisfactory answer.

CHAPTER III.

GENERAL DISCUSSION OF THE DESICCATION QUESTION.

Section I. — *Introductory.*

It will be proper, at the present stage of our investigation, to recapitulate what has been set forth and shown to exist, in connection with the problems of climatic change, in the preceding chapters of this work, and in a former one (the Auriferous Gravels), to which frequent reference has already been made, and to which the present volume may properly be considered as supplementary.

As one of the important results to which we were led by our extended examination of the detrital formations resting on the western slope of the Sierra Nevada, we have the — as it appears to the present writer — undoubted fact presented to us of the former existence, throughout that region, of much larger rivers than those whose channels now furrow that slope. These rivers had, however, on the whole, pretty essentially the same gathering-grounds which their present much diminished representatives have; hence it follows, as a matter of course, that the former precipitation must have been very considerably larger than it now is. This condition of things prevailed during a portion of the Tertiary epoch, probably during a large part of the Tertiary, and certainly during the later Pliocene. If it cannot be definitely stated that this increased precipitation also prevailed during the earlier Tertiary period, it is only because Eocene fossils have not been distinctly recognized as occurring in the detrital formations in question, so that the means of going back to the beginning of the Tertiary epoch are not furnished. There is no evidence, however, that the precipitation over the region in question was, during the earliest portion of the Tertiary, any smaller than it was later on in that period; on the contrary, there is some reason for supposing it to have been larger. So much has been set forth in detail in the Auriferous Gravels.

Pursuing our investigations still farther, we have seen, as described in the first chapter of the present volume, that long after the deposition on the flanks of the Sierra Nevada of the gravels which belong to the period of increased precipitation, and after the present diminished rivers had worn — in large part, at least — their deep but narrow channels down the sides of the range, there came a time when the higher portions of the Sierra were covered with accumulations of snow, from which glaciers of great size extended down the valleys, some of these icy masses attaining dimensions not much, if at all, inferior to those of the Alps at the present day. It was farther shown that these glaciers had now almost entirely disappeared, only the faintest traces of ice being left in a few localities, and especially about the north side of the summit of Mount Shasta, while reasons were adduced for believing that this disappearance of the ice has taken place within a very recent period, and most certainly since the appearance of the human race in that region. In regard to the snow accumulations of the range in question, it was shown that they vary greatly in amount from year to year; and that, although they never disappear entirely from the whole of the Sierra, even after the occurrence of a cycle of abnormally dry years, they sometimes shrink into entire insignificance, as compared with the mass of the range, occupying only small sheltered nooks on the summits of the higher elevations.

With this foundation of facts, observed and studied with great care in the region which was the especial field of work of the present writer for some fifteen years, the attempt was made to find out how far a similar condition and succession of phenomena could be traced in other regions; and first in those adjacent to the Californian Sierra; then, later, in others more distant; until, finally, the inquiry extended itself so as to embrace the whole earth; and very naturally and properly, for the subject of climatic change is one which cannot be discussed with satisfaction while only narrow areas are under consideration, as must be evident from the nature of the phenomena themselves, the climate of any one locality being the result of a complex series of events, many of which have taken place at a great distance from the special locality where they become sensible to the inquirer. In thus extending the investigation over regions outside of California, the present writer has not been obliged to depend entirely on the work of others, although such has been consulted and freely used; he has been assisted by his own investigations, which at various times during the past forty years have been extended over a considerable portion of North America, and have also embraced the most important glaciated regions of Europe.

This extension of the investigation begun in the Sierra Nevada has furnished us with interesting results, in a great measure corroborating those obtained on the Pacific slope of the continent. That the diminution of the rivers flowing down the western slope of the Sierra could be so fully proved, was due to the peculiar facilities offered by the extremely numerous and extensive mining operations carried on in and about the former channels of these "buried rivers," as they have sometimes been called; and although the same kind of proof could not be furnished bearing on the diminution of the precipitation in portions of the continent adjacent to California, a large body of facts was brought forward showing that an extensive area of country west of the Rocky Mountain range was formerly covered by water, in the form of lakes, which lakes have either disappeared altogether, or become greatly diminished in area, this diminution having taken place during the Tertiary epoch, and having been continued almost if not quite up to the present time, thus indicating important physical changes — either climatic or orographic, or both together — as marking the Tertiary and Recent periods over a vast area of territory, outside of the State of California, as well as within it. The difference between the results arrived at in the Sierra Nevada and those obtained in the region between the Sierra and the Rocky Mountain range was chiefly this: that in the former case we had proof of a diminution of precipitation independent of any orographic changes; while, in the latter, the phenomena were more complicated, orographic changes being not so easily disentangled from climatic ones.

In regard to the period of the extension of the glaciers over the crest of the range of the Sierra Nevada at a period subsequent to that of former increased precipitation, we found, on examination, as detailed in the first chapter of the present volume, that a precisely similar condition of things took place all over the Cordilleras, north of a certain latitude. The highest portions of the Rocky Mountains and the very highest summits of the loftiest ranges of the Great Basin were, at a very recent geological period, covered by snow, from which were formed glaciers rivalling in magnitude those of the Sierra itself. And as in the last-mentioned range, so in those farther east, only the most diminished representatives of the ancient glaciers remain; although the peculiar markings and other proofs of their former much greater extension are preserved in such freshness as to lead to the belief that they are of extremely recent formation.

All of what has been stated, in regard both to the former glaciation and the desiccation of the region of the Cordilleras, has been found out within a very recent period, nothing at all having been known of either change of conditions previous to the commencement of the California Survey in 1860. But the fact of the former glaciation of portions of the country east of the Mississippi and about the Great Lakes had been familiarly known, and much commented on, twenty or more years before that time. And the same thing is true of certain parts of Europe: glaciers — both as at present existing and as occupying a much larger area in former times — have occupied a large share of the attention of geologists during almost half a century.

To the reader, then, it might have seemed natural that the phenomena of extinct glaciation in Northeastern North America and in Europe, as well as in other parts of the world, should have been described in connection with that which has been said on the same subject in a preceding chapter, in reference to the region of the Cordilleras. This, however, was not necessary, or even possible. For, in the first place, the body of facts collected by various observers is too large to be brought within such moderate space as the present volume affords; and, in the second place, the position of the present writer with regard to the phenomena of extinct glaciation in the Cordilleras was a peculiar one, rendering it justifiable in him to endeavor to collect together, for the first time, the principal facts, so that a clear idea might be had of their scope and bearing; while at the same time attention was called to some of the remarkable errors into which observers inexperienced in this department of geological investigation had fallen: this it was necessary to do, since leaving these mistakes uncorrected would have much increased the difficulty of the subsequent discussion. To a rapid review of the principal facts connected with both extinct and present glaciation our attention will be naturally directed in the last chapter of the present work, when, having set forth the principal facts connected with the desiccation of a large portion of the earth, and endeavored to account for the same, it will have become necessary to show that the former greater extension of the glaciers over certain regions is not necessarily a condition of things in conflict with what appears to the writer to have been the course of events during the geological ages preceding and following the so-called glacial epoch.

That, on the other hand, the phenomena of desiccation should have been taken up as manifested in other regions than in the Cordilleras, as has been done in the preceding chapter, is to be explained by reference to the facts that the diminution of precipitation, and the other physical changes connected with the decrease of the water-surfaces and general drying-up of the earth, are matters of more wide-spread occurrence, and of vastly greater importance, than is the diminution of the glaciers in certain limited regions. These facts have never, as the writer thinks, been presented in their connection with each other, or examined from the right point of view; while "glacial geology," on the other hand, may be said with truth to have formed the staple of the geological journals and text-books during the past few years.

The problem first to be attacked, then, in the prosecution of this investigation is, What means the desiccation which has been shown, beyond doubt, to have taken place during the later geological ages, and to be continuing during the historical period? Is it something which is due to orographic causes; or to climatic changes, independent of size, position, and elevation of the land masses? Or, on the other hand, has this diminution of moisture been the result of both climatic and orographic causes acting in concert with each other; and, if so, is it possible to say what part each of these sets of causes has taken in bringing about the indicated desiccation? Still farther, is it possible to assign a probable cause for such change of climatic conditions as it may have become necessary to assume as having occurred? These are the principal questions to which it is proposed that our attention shall be called in the present chapter.

In what has just been said the writer has not intended to suggest that the phenomena of desiccation in certain parts of the world have not attracted much attention, and been the object of more or less discussion. The quotations given in the preceding chapter afford evidence enough that such remarkable events could not fail to arrest the attention of observers. What is asserted here is this: that these phenomena have not been considered in their *ensemble*, but rather as simply local manifestations, independent of any common cosmic cause; or as being of a transient nature; or, again, as being something entirely exceptional, and not to be brought into harmony with the ordinary course of nature.

By far the larger number of writers who have discussed the subject of desiccation have looked upon this remarkable change as something quite by itself, and as having no connection with precedent changes in the geological history of the world! A few, however, have to some extent treated in a more general way the remarkable phenomena which have been indicated in the previous chapter: to the views advocated by both these classes of investigators our attention will be given in the present chapter. The views of those who look upon the climatic change in question as in no wise connected with any orographic or cosmic cause may properly be first examined, as they can soon be entirely set aside, and removed from the field of our discussion. This class of authors, which, as has already been stated, embraces by far the larger portion of those who have written on the subject of desiccation, includes all who look upon the drying-up of various regions as the work of man, and not of nature. It is true that these writers often have a very vivid idea of the magnitude of the change which is going on, in its effects on the welfare of various peoples; but they neither connect it with anything in the geological history of the past, nor do they perceive that it is something over which man has no control. On the contrary, they believe that man has brought this ruin on himself; and that, if he would only stay his destroying hand, the land, once fertile and crowded with a prosperous population, but now desert and abandoned, would again blossom as a rose, and again give support to thriving millions. Of the extent to which this opinion has become a matter of popular belief, and of the way in which it pervades all classes of the community, having impressed itself most deeply on the minds of scientific observers as well as of popular writers, the following extracts, compiled from a variety of sources, will serve to convey some idea. These quotations are, to a certain extent, analogous in their bearing with those given in the last section of the preceding chapter, but are not repetitions of the same. There, the dominant idea was, to show how the reality of the desiccation had impressed itself on the minds of travellers and geographers; here, the intention is, to show how strongly and positively various writers have expressed themselves to the effect that it is man's hand which has wrought the ruin.

The first citation may be from the works of Bernard Palissy, the eminent potter, who died in 1589.* He says, in answer to his own question, "'And why thinkest thou that it is so bad a thing thus to cut down the forests?' I cannot sufficiently detest such a thing, and do not call it a crime, but a malediction, and a calamity for all France, for when the forests have all been cut down, all the arts will necessarily be brought to an end, and the artisans will have to go and eat grass like Nebuchadnezzar." †

* In the Bastille, where he was awaiting execution for the crime of being a Calvinist.

† Œuvres de Palissy. Paris, 1844, pp. 88, 89. This writer's extreme horror of cutting down trees does not, however, seem to have been so much based on a fear of resultant desiccation as on that of an absolute dearth of material for use in the arts.

Dr. F. Simony, of Vienna, says: "Of Persia we learn that, although this country is two and a half times as large as the Austro-Hungarian monarchy, it has now not more than six or seven millions of inhabitants; and that, in spite of the thinness of the population, it is a region often devastated by famine. It is reported that in the years 1871–72 between one and a half and two millions of people died from starvation. And yet this kingdom once was counted among the mightiest and most flourishing states of Asia, while the yield of its cultivated land, thanks to its thorough system of irrigation, was enough to support a population many times as large as that now existing there. *And this has all happened in consequence of the continued destruction of the forests in the mountains, which now stand there naked and barren.*" * [In Folge der fortgesetzten Verwüstung der Wälder in den Gebirgen, welche gegenwärtig nackt und dürr dastehen.]

At the International Congress of Land and Forest Culturists, held at Vienna in September, 1873, instances were cited showing that, "*in consequence of clearings*, there has been a gradual decrease in the depths of the large streams of all countries." †

On the 27th February, 1856, the subject of the change of climate consequent on the removal of forests was brought before the French Chamber of Deputies by M. Ladoucette, deputy for the Moselle, who asserted that in the whole of the Eastern Pyrenees and the Hérault the destruction of timber had been calamitous. The temperature became higher, wells and water-courses diminished, while the dryness of the climate was greatly increased. According to Professor Laurent, of Nancy, desolation has been brought upon the nations of the East,—"upon Babylon and Nineveh, Thebes, Memphis, Carthage, Palestine and the Troad" *by the loss of their forests*.‡

The number of quotations, to the same effect, and referring to the desiccated regions of Asia and the countries bordering on the Mediterranean, could be multiplied indefinitely. Some additional ones have already been furnished in the preceding chapter, in cases where the description of the phenomena, as given by some authors, could not readily be separated from their theory of the causes of the same. A few more citations will be made from authors writing in or of America, in order that it may

* In a little work entitled "Schutz dem Walde"—Protection for the Forests—published at Vienna, in 1878, p. 15.

† Quoted from F. B. Hough's Report upon Forestry. Washington, 1878, p. 292.

‡ Quoted from Hough's Report, p. 293. The writer has taken the liberty of italicizing a few words in each of the quotations.

not be assumed that this popular belief is in any way limited to the Old World.

Professor Hartt says: "The wholesale and careless destruction of the forests on the Brazilian coast, unless put a stop to, will in the end work a sure ruin to the country. Brazil owes her climate and fitness for agricultural purposes to her forests, and it is absolutely necessary that they should be preserved over a very large part of the country, especially on the coast. The climate of the Bahia has already suffered from the destruction of the forests of the Reconcavo, and the burning over of the plains. But I fear that Brazil will learn this fact only when it is too late." *

Mr. E. D. Mathews, in describing the lakes near Vacas, in Bolivia, says: "These are probably parallels, on a small scale, of Lake Titicaca, in the northwestern corner of Bolivia, or of the lake of Valencia, in Venezuela, lakes that are known to be decreasing rapidly from extended agriculture, aided, in the case of Lake Valencia, by denudation of the forests." †

Mr. Wilson Flagg says, in reference to this topic: "The same indiscriminate felling of woods has rendered many a once fertile region in Europe barren and uninhabitable, equally among the cold mountains of Norway and the sunny plains of Brittany." ‡ Farther on, the same writer remarks: "Nature clothes all parts with trees, and leaves it to man to improve or to ruin the climate according as he is wise or stupid. Nations in most cases have ruined it and then sunk into barbarism; for civilization has never, in any country, long survived the destruction of its forests." §

Mr. F. B. Hough, chairman of a committee appointed by the American Association for the Advancement of Science, to report on the cultivation of timber and the preservation of forests, after the presentation in his report of a heterogeneous mass of material in regard to climate and forestry, says under the heading "What shall we do to be saved?" — "Such being the consequences of an improvident and indiscriminate clearing off of the timber, the question naturally arises: 'What shall we do to be saved?' The answer is plain and obvious: 'Plant trees.'"

It is proper for certain purposes where scientific accuracy is not required and where it is desirable to draw inferences as to popular opinion, to quote

* Geology and Physical Geography of Brazil. Boston, 1870, p. 321.

† In "Up the Amazon and Madeira Rivers." London, 1879, p. 245.

‡ The Woods and By-Ways of New England. Boston, 1872, p. 109.

§ l. c., p. 142.

from newspapers. In publications of this class hardly a day passes that some paragraph may not be noticed, either original or going the rounds, as ordinary newspaper extracts do, — especially in the case of such as contain incorrect statements of fact, or errors of some other kind, — without contradiction, ascribing alterations of climate in various regions to removal of the forests. These alterations are usually indicated as being wide-spread, and of a most disastrous nature. One or two quotations of this kind will answer the purpose of making known the character of the popular impression on the point in question, as evidenced by the gist of innumerable newspaper paragraphs. The first is from a leading article in what is usually considered a highly respectable organ of public opinion, published in a city professing to be one of culture. "The Arboretum [near Boston] was founded as a scientific establishment in the belief that the information it could gather and disseminate would add something at least to the world's knowledge of the relation of the forest to man in its climatic, physical and economic aspects, and of the methods which, sooner or later, must be adopted to protect our forest growth, unless the United States is to be allowed to sink to the commercial and social level of the deforested countries of the Mediterranean basin." *

The New York "Nation" thus speaks, in its usual peremptory tone, on the subject of "our 'protected' forests": † "Scientific men *agree with great unanimity* that the preservation of extensive forests is vital to the prosperity of a large part of the country. . . . . Moreover the prosperity of the West is an agricultural prosperity directly connected with its forest growth, for one of the few means of moderating these violent excesses [of climate — phenomena of excessive winds, rain-fall, and drought having been described in graphic language in the omitted sentences] and keeping up the even distribution of the necessary moisture is by forests. . . . . In California the destruction of the trees has been so reckless that over great tracts of land the soil, stripped of its natural protection, is burned by the sun and powdered by the wind into a hopeless desert." ‡

From the above it will be seen that the prime cause of the desiccation and the ensuing ruin of various regions is usually considered to be simply the removal of the forests. There are writers, however, who take a somewhat

* The Boston Daily Advertiser, number for Nov. 29, 1881.

† In the number for Jan. 5, 1882. The italics are of the present writer's adding.

‡ The statement in the last sentence quoted is not true, as a matter of fact, and reference will be again made to it farther on.

different view of the matter. According to them, man in his personality, and in all his works, is a destructive influence; and old and long inhabited countries must, in the nature of things, go to perdition. Sometimes it is "over-irrigation," at other times "agriculture," in which term, of course, the removal of the forests may be included. Occasionally we find an author, even among those of scientific education and of ability, who evidently looks on civilized man as being, in some mysterious way, antagonistic to nature, so that intellectual development and multiplication in numbers of any race carry with them the seeds of future destruction of the nation thus for a time riding on the wave of prosperity. Farther reference will be made to this idea in the course of the discussion of the question whether the changes of climate indicated as having occurred in the various regions specified can be due to removal of the forests.

SECTION II. — *Is Desiccation the Result of partial or entire Removal of the Forests by the Hand of Man?*

It seems convenient to discuss this question by itself, before proceeding to take up other more complicated theories which have been advanced by various authors. If, as the writer believes, it can be clearly shown that man has not been able to effect a noticeable or important change in the climate of any region, and that the human race is no way responsible for the changes which have brought and are bringing ruin upon those countries which, once prosperous, have now sunk into comparative decay, then it will remove one of the alleged complications, to have this branch of the inquiry set aside, so as to leave a better opportunity for investigation in other directions. Not that all can be brought forward at the present stage of the inquiry which bears on this question; some points will be better understood after the general discussion of the physical causes influencing precipitation, both in amount and distribution, which will come up in the next section but one. But, without exhausting the subject at present, it will be a step gained to have acquired a clearer idea of some of the evidence going to show that the question of desiccation is one essentially removed from the domain of man's influence; and that it is incumbent on the investigator to seek in other directions for some vastly more general and potent cause of the phenomenon.

It will be desirable, as preparatory or introductory to the present inquiry, to say something in regard to the distribution of forests on the earth's surface, and the climatic conditions which accompany and may be assumed to have influenced this distribution. But a limited amount of investigation is required in order to have it made clearly apparent to the candid mind that the character of the flora of any region is most powerfully influenced by variations of the climate, and especially by changes in the temperature and the amount of moisture. Summed up in a few words, it may be stated that extreme cold and extreme dryness are unfavorable to the development of vegetation. In the case of temperature we see this almost equally well illustrated, whether we journey toward the Polar regions, or rise on the sides of lofty mountains, the decrease of temperature manifesting itself, in a most marked degree, by corresponding changes in the vegetation. The forest trees which are recognized as typical of warm climates disappear; those characteristic of colder regions make their appearance. These, in their turn, become more sparsely distributed and dwarfed in size, and finally give out altogether; some grasses and flowering plants maintain their hold up to still higher and colder latitudes; and finally all these disappear, and only the lichens remain, of which no land, however far north it may lie, has ever been found entirely destitute. Of a similar character is the decline of vegetation as we ascend the slopes of high mountains. Trees first disappear; higher up, grasses and flowering plants do the same; while the lichens maintain their hold to the last, and often until the line of eternal snow is reached. That these effects are mainly due to temperature changes can hardly be doubted. The disappearance of the trees is coincident with a diminution of the temperature, and is not accompanied by a corresponding falling off in the amount of precipitation. On the contrary, the giving out of the arboreal vegetation may and does take place where moisture is abundant, as on the slopes of high mountains between the forest line and the snow line. The same condition reveals itself most clearly when we consider carefully the position of the timber-line along the northern edges of the great land-masses of the northern continent.

But, on the other hand, it is not possible to deny that the presence or absence of moisture has much to do with the character of the vegetation; and no one can doubt that the distribution of forests over the earth's surface is largely dependent on the position of the areas of greater or less precipitation. A very large rain-fall may coexist with an abundant forest growth; and so, as it appears, an abundant arboreal growth may be found in regions where the precipitation is comparatively small in amount. Great differences are found to occur in the rain-fall of forest-covered areas; so that it seems hardly possible to say that any quantity of moisture is too great to allow of the growth of trees, provided that the excess has an opportunity to run off the surface, and does not stand upon it so as to form swamps or morasses. At all events, it is a fact that forests are abundantly developed in regions where the rain-fall exceeds 100 inches, and sometimes in those where it much exceeds this amount. It is also true that there are dense forests in regions where the total precipitation (in rain and melted snow) does not much exceed twenty inches. Where the amount falls below this last-named figure, forests do not thrive; but the grasses usually do so, and often in the greatest vigor and abundance. An inspection of a rain-chart of the earth, and a comparison of the position of the rainless and drier areas with that of the belts or tracts destitute of trees, will be sufficient to show at once that, in a general way, regions where the rain-fall is deficient, or falls below twenty or twenty-five inches, are those where trees are least developed; and also that a vigorous growth of grasses may be found where the precipitation is considerably below twenty inches.

It will perhaps surprise the reader to be told, as he may be with truth, that certainly more than a quarter, and probably more than a third, of the land surface of the earth belongs to the region in which the grasses and carices, or a shrubby vegetation, constitute the natural growth, while trees are almost entirely absent. Asia is the continent on which the amount of treeless area is proportionally largest; but there are more than two millions of square miles which may properly be classed in this division in South America, and more than half that number on our own division of the continent.

Absolute deserts — that is to say, regions where no vegetation of any kind covers the surface — are of very much more limited occurrence than are the steppes above described. Even in localities where the cold is greatest, and also in those where the heat is most intense and the atmosphere least moist, some kind of vegetable life may continue to exist, provided the surface be not a movable one. Thus in the Sahara, which is usually accepted as a typical desert region, there are large areas which are covered by a shrubby vegetation, sparsely distributed, it is true, but not altogether absent. The really desert regions are those over which movable sands form a heavy covering, continually shifting their position as urged forward by the driving winds. The same is the case with the desert portion of Arabia; and these accumulations of sand seem to have come from the disintegration of sandstones, with which the areas in question were originally underlain.

Another cause of the formation of really desert areas is the drying up of lacustrine areas covered by very saline water. In such cases the dry bottom of the old lake is at first too strongly impregnated with mineral matter to allow any vegetation to take root and flourish. A long exposure to atmospheric influences would, in such cases, be required to enable the soil to get rid of its excess of saltness; and as such cases of desiccation must necessarily be confined to regions of small rain-fall, it will be easily understood that such desert areas must, as an ordinary thing, remain unoccupied by vegetation for an indefinite period.

Since moisture is essential to the vigorous growth of trees, so that very dry regions are not, as a general rule, covered by forests, it will not be difficult to understand why treeless areas are usually found in the interior of the great continental masses, as is so well illustrated by the position of the plains of North America and that of the pampas and llanos of the southern division of the New World. As will be more fully explained farther on, the edges of the continents are the regions where the larger portion of the rain-fall, on the land, takes place. To this rule there are but few exceptions; the most striking one is the existence of a rainless belt along a considerable part of the west coast of South America, a condition of things chiefly dependent on the position of the chain of the Andes, in that region, with reference to the trade-winds.

Besides excessive dryness and cold, there is another cause which is effective in preventing a natural growth of forests over certain areas, which are not unfrequently of very considerable extent. This condition sometimes occurs independently of other agencies, so that certain regions remain treeless when precipitation is abundant, and the temperature conditions perfectly favorable to the growth of arboreal vegetation. In other places the cause in question is more or less effective in combination with some other condition tending to bring about the same result. It is the mechanical texture of the soil, and especially its fineness, to which allusion is here made. In the region of the so-called *prairies* of the Mississippi Valley, especially, there are very large areas where the rain-fall is ample, but where, over a large portion of the surface, trees are wanting, their place being supplied by a vigorous growth of grasses. Here, moreover, it is evident enough that temperature has nothing to do with the absence of the forests. Examination, however, shows that the soil in such regions is of an exceedingly fine texture; so much so, that it polishes the tools with which it is cultivated, instead of scratching them. Careful investigation also reveals the fact that all through these prairie regions the occasional presence of clumps or belts of trees is invariably associated with the existence, in such localities, of a coarser variety of soil. For instance, a grove — as such isolated patches of forest are usually called — in which the trees are thickly crowded together and flourishing will be seen in the midst of an area of perhaps hundreds of square miles in extent over which not a single tree is growing. Examination of such a locality will show at once that the grove covers a patch of gravelly soil, while the surrounding treeless area, which is usually lower and flatter than the spot occupied by the trees, is covered with the fine prairie soil, the character of which is so well known at the West, and which has been repeatedly described in the different State geological reports.

In regard to the effect of this peculiar fineness of the soil in preventing the growth of forests in the "prairie region" of the Mississippi Valley, the writer speaks from careful and long-continued examination of that portion of the country. That the same conditions hold good in other regions, and especially over a large area of the treeless part of the South American continent, seems, also, hardly to be doubted. There are extensive areas in that country where the precipitation is certainly more than abundant, and where the temperature conditions are perfectly favorable, yet where grasses and various flowering plants and shrubs flourish, to the exclusion of trees. Here the fineness of the soil seems to be the essential cause of the peculiar character of the vegetation, as it most certainly is in the prairie region of North America.

The peculiar influence of texture of soil in favoring the growth of the grasses in preference to arboreal vegetation, although advocated many years ago by the present writer,* has been overlooked by most of the investigators into problems of this character, and another theory has been maintained, especially by the distinguished German physical geographer Peschel. This theory is to the effect that it is not the insufficiency of moisture, in such treeless regions, which prevents the growth of the forests, but its unequal distribution through the year. This theory was applied by Peschel particu-

* In the Geology of Iowa, 1858, Vol. I. p. 24. See, also, The American Naturalist for October and November, 1876.

larly to the South American pampas and llanos; but was also advocated by others as the effective cause of the existence of the treeless areas in the prairie regions of our own country. In the latter case, however, the publication by the Smithsonian Institution of the statistics of rain-fall in the United States, as elaborated by Mr. Schott with great care and critical acumen, rendered it possible to declare with the utmost confidence that there was no such irregular distribution of the precipitation through the year as had been taken for granted, without inquiry or investigation, by those promulgating the theory in question. On the contrary, it appeared certain that the rain-fall in the prairie States was not only ample in quantity but as regularly distributed through the year as it was in adjacent heavily wooded regions. Indeed the existence of forests, hardly surpassed in grandeur by any in the world, along the slopes of the Sierra Nevada of California, where the precipitation is as irregularly distributed as possible, would, of itself, be sufficient proof that the theory advocated by Peschel must, to say the least, be looked on with great suspicion.*

Bearing in mind the foregoing remarks as to the vastness of the area of treeless land on the earth, and the nature of the causes by which this condition of the surface has been brought about, the reader will be prepared to examine the question whether it is possible to account for the phenomena of desiccation, as described in the preceding chapter, by ascribing it to man's interference with the course of nature, — a theory shown to be so widely prevalent at the present time.

It must be evident to every one that, at least as a general rule, the treeless areas of the earth are such on account of their position with reference to the distribution of the rain-fall or of temperature, or else on account of the peculiarities of the soil by which they are covered. In fact, it is not known that any one has seriously advocated the theory that the steppes of Asia, for instance, have been made what they are — as to vegetation and physical character — by the agency of man. Neither has it occurred to any one to maintain that forests formerly extended quite to the edge of the sea along the northern coasts of North America and Europe, and that in conse-

* The physical-geographical and statistical maps published by the Russian Government, on which the distribution of the forests and the character of the soil of that country are indicated by colors, show the most remarkable coincidence between the position of the lines bounding the forest-covered area on the south and that of the region of the so-called "tschornozem," or black earth, on the north. This peculiar variety of soil, as is well known, is characterized not only by its color, but by its extraordinary fineness, just as is that of the prairie region of North America.

quence of their extermination by man the climate of those regions has become cold, inhospitable, and unfavorable to arboreal growth, as we now find it to be. No more can it be assumed as *prima facie* true, that any part of the earth's surface, if now destitute of trees, has been rendered so by the hand of man. Evidence, clear and convincing to that effect, must be furnished, before credence can be given to statements of this kind. More than this, if it can be shown that the trees which formerly covered any given area have been cut down, and that the climate in such a locality, once favorable, has now become of a character hostile to the prosperity and intellectual development of man, it remains still to be proved that it is the removal of the forests which has been the effective agent in bringing about this changed condition of things.

If it be true that the desiccation of certain regions, which seem on trustworthy evidence, as set forth in the preceding pages, to have become drier during the historic period, was begun long before man could have been in existence to interfere with nature's work, then we shall have strong reason to infer that what was begun without the interference of man, and continued for an indefinite period without it, may be still going on in the same way, and that we are only the witnesses of the continuous working of an agency which would have remained effective even if the earth had never become inhabited by man or animal.

That the drying-up of the Central Asiatic and the Cordilleran regions is a phenomenon which was begun long before man could have interfered with the course of nature, seems evident from the facts which have been set forth in the preceding chapter. Whether we consider the diminution of the Tertiary rivers of California to their present comparatively insignificant size, the dwindling away of the lacustrine areas of the Great Basin, or the similar condition of things shown to have been begun in the heart of the Asiatic Continent at least as early as the Tertiary period, we are forced to admit that we have to do with a phenomenon as far beyond man in the length of time it has been in operation as it is beyond the scope of his powers from the point of view of its magnitude.

No one has ever suggested that the drying-up of the region of the Cordilleras was due to the action of man; neither has a similar claim been urged, to any considerable extent, with regard to the vast area of Central Asia where the phenomena of desiccation present themselves in such a striking manner. Neither has it been suggested with reference to the great diminution of the lakes of Central Africa described by Livingstone. It is almost exclusively in reference to the present condition of the region bordering the Mediterranean that the theory in question has been urged, and it is from their hapless fate that the inhabitants of other regions, not yet suffering in like manner, are warned. The reasons of this will be obvious enough. The intimate connection of that region with the development of the human intellect renders everything connected with its past history and present condition a matter of profound interest to other nations who have received from that quarter the light of civilization. Few care enough for the past or present condition of Equatorial Africa to investigate the changes of climate it may have undergone; and certainly historical research on such a point would there be quite unavailing. The same may be said of the southern portion of Central Africa, of Central South America, and of most other areas where the phenomena of desiccation have been displayed on a large scale. It is only around the Mediterranean, and in the region to the east of it, that we can ever expect any historic light of importance on this question. Some special inquiry ought therefore to be made from a historical point of view into the evidence which those countries are able to furnish bearing on the problem before us.

It might be supposed, from the positive manner in which it is stated by many that the cutting down of the forests in the countries bordering on the Mediterranean has brought them to their present condition, that historic records showed that that whole region was once heavily covered by a growth of trees. This is by no means the case: it cannot be proved from the works of ancient authors that those countries have ever, within the historic period, been even moderately well provided with forests. The remains of petrified trees, which are found over portions of this area, belong to a prehistoric period, and probably to the later Tertiary. No representations of the scenery found among the monuments of Egypt give us authority for placing that country among the forest-covered regions.

Mr. Burton evidently believes that, in the case of the region explored by him with special reference to its ancient mining work (the Land of Midian), — where he thinks that mining operations were carried on up to the seventh century of our era, — the necessities of such work demanded the use of a large amount of fuel, and that this would prove that the country was formerly well clothed with forests. This, however, need not have been the case, as may be illustrated by reference to what the writer has himself observed in the region bordering the eastern slope of the Sierra Nevada. Here is a country of small rain-fall, too dry ever to be thickly inhabited, and which at first sight, when it began to be settled by a population called thither by the richness of its silver-mines, would have been described as a treeless region. Nevertheless, for several years after the mines on the Comstock Lode, at Virginia City, were opened, and when the very extensive mining and metallurgical operations carried on there demanded a very large amount of wood, this was mainly furnished by the adjacent mountains. The seemingly treeless country did yield, for some time, from the depths of its almost inaccessible gorges and cañons, a very large supply of fuel. Such we may imagine to have been the case in the Land of Midian, if it can be proved that the kind of mining operations carried on there did really demand any considerable amount of wood, which, as would appear from the nature of the metal obtained, — gold, namely, — is not so certain. At all events, we have in the experience of the Nevada silver-mining region evidence bearing on the point in question. That country has, within twenty years, and under the observation of the present writer, been thoroughly stripped of its scanty forests. That this, however, has in any way changed the character of the climate, or rendered the region less habitable than it was before, is not evident from any facts reported or observed. That fuel has had to be brought from greater and greater distances to the various smelting and metallurgical works, is plain enough; and that, in consequence, its price must have greatly risen, when other means or facilities of supply were not forthcoming, is also not to be denied. This, however, has no connection with anything claimed as the result, in the Mediterranean region, of disforesting the country. No doubt if rich mines could be proved to be still existing in the Land of Midian, fuel would be got to them in some way; and if rich enough, they would be worked with success.

Statements like that quoted on a preceding page, to the effect that the climate of portions of the Pacific Coast has been changed for the worse "by the reckless destruction of the trees,"* are entirely without foundation in fact. They well illustrate, however, the facility with which evidence is manufactured to support any theory which may, for some reason, have secured a hold on the popular mind. The so-called Desert of Southern California — the only portion of the State where the "ground is burned by the sun and powdered by the wind into a hopeless desert" — was not long since covered by

* See, *ante*, p. 163.

lakes or by an inland sea;* and of course it can never have been disforested. All about the Bay of San Francisco the removal of the timber has gone on, within the past few years, with the greatest rapidity; more so than anywhere else in the State. But there is no statistical proof that the rain-fall in that region has been diminished since the occupation of it by an English-speaking people. On the other hand, it is believed that there is no portion of this continent which is considered by its inhabitants to have so well founded a claim to be recognized as an earthly paradise.

An excellent opportunity appears to the writer to have been offered in New England for throwing light on the question whether disforesting a country does really change the character of its climate or materially diminish its rain-fall. There is no doubt that New England was, not long since, a country well covered with a forest growth. That it was such when its settlement by the whites began, 250 years ago, is a generally admitted fact. The aboriginal inhabitants had not in any perceptible degree taken from it, during their occupancy, its character as a great forest.† For the purposes, however, of the present illustration, attention will be called to the southwestern portion of the region in question, or the area included within the States of Massachusetts, Rhode Island, and Connecticut, and the southern half of Vermont and New Hampshire, embracing in all about 25,000 square miles.

At the present time the area designated has been so far disforested that nearly all of it is placed on Professor Brewer's "Map showing in five degrees of density the distribution of woodland within the Territory of the United States" ‡ in the lowest of those grades, having thus been apparently reduced from the highest to almost the lowest condition, as respects the abundance of its timber, since the settlement of the country by the whites.

That a large part of this destruction of the forests has taken place within the past fifty years, and since railroads were generally introduced, seems to the writer a not unreasonable statement. His own recollections would

* As mentioned on pp. 104, 105.

† See, on this point, Palfrey's History of New England, Vol. I. p. 16. He says: "The woods were so vast that the early writers describe them as covering the country," — quoting, in support of this statement, from Higginson, in Mass. Hist. Coll. I. 117: "Though all the country be, as it were, a thick wood in general, yet in divers places there is much ground cleared by the Indians." Also from Josselyn's New England's Rarities: "The country generally is . . . . extremely overgrown with wood;" and from Early Records of Charlestown: "An uncouth wilderness full of timber." Here we have the word "timber," which is in common use all over the United States instead of forest.

‡ In Walker's "Statistical Atlas of the United States."

justify him in stating, at least, that the change brought about within forty or fifty years in regard to the comparative areas of forest-covered and unwooded country in Southern New England is very great. This period of forty or fifty years is insisted on, because the observations for rain-fall taken in this region go back just about as far as that. If, then, disforesting a country is followed by a marked decrease of the precipitation in the region cleared of its trees, we ought to find some evidence of the fact in the case of Southern New England. The statistics, as given by Mr. Schott for numerous stations within the area specified, do not, however, in the least indicate any diminution * of the rain-fall during the past half-century; on the contrary, the conclusion is reached that, for the Atlantic sea-board, from Maine to Virginia — this area forming Group I. of Mr. Schott's division of the whole country into climatologically allied regions — an increase of rain, on the average, since 1835, is "distinctly indicated." A similar condition of things is reported for the adjacent region of New York, where also, as well as in Southern New England, very extensive clearings have been made during the past fifty years.

These results are more valuable, inasmuch as the average annual rain-fall within the region in question is not very large, and it could not be considerably diminished without disastrous effects. The precipitation at Providence, for instance, from which place we have one of the longest and best series of observations which has been made in New England, the average from 1832 to 1867 was 41.54 inches, with a pretty regular distribution, the amount never falling below thirty, or rising above fifty-five, inches. A diminution of this amount to the extent of one third would undoubtedly have very serious consequences, while taking off ten or fifteen inches from the rain-fall of a region where the annual average was over a hundred inches would probably not be perceived at all, except as instrumentally recorded.

Under any circumstances, our own country does not furnish, in any part of its vast area, any support to the theory that removing the forests brings about a condition of barrenness and desolation. No one would say that any portion of New England had become barren or desolate, or had been rendered any less capable of supporting a dense population than it was at the time of the arrival of the first English-speaking people upon its shores.

It has been supposed by some that the idea of a diminished rain-fall as a

* The observations used by Mr. Schott go back, in the case of one station, to the year 1804; records, however, soon began to be kept at additional points, and the number increased rapidly from 1830 on.

necessary consequence of removing the forests had found support in certain alleged facts going to prove the converse of that theory. If it could be shown that causing trees to grow in comparatively rainless regions had brought about a more abundant precipitation, then it would be allowable to infer that their destruction would have just the opposite effect. In regard to this point, however, there is in reality but little chance of obtaining valuable evidence, for — thus far, at least — no attempt has been made on any very large scale to reproduce forests artificially where they are once supposed to have existed, and where now they are certainly absent. To show the ease with which evidence of the kind desired for the support of the theory in question can be manufactured, reference may be made to Egypt, a country in regard to which it is always being asserted in popular works of travel, and especially in the newspapers, that its climate had been decidedly changed, of late years, by the increased cultivation of trees. The statements to this effect do not, however, at all bear examination. The statistics are confessedly imperfect; but, as far as they do go, they prove, if anything, a deterioration of the climate, since the beginning of the present century, rather than a gain in the amount of moisture. Captain Burton says, in reference to this point: "An idea demanding correction is the popular fancy that the frequency and quantity of rain in Egypt have increased of late years by the planting of trees. Clot-Bey and M. Jomard declared that, despite the vigorous measures of Mohammed Ali Pasha, who alone laid down three millions of mulberries, the fall measured what it did forty years before. The Meteorological Tables, for the three years of French occupation, drawn up by M. Coutelle, compared with the recent observations of Mr. Destoviches, show no sensible variation. Between A. D. 1798 and 1800, the rainy days averaged fifteen to sixteen; while, during the five years between 1835 and 1839, it diminished to twelve – thirteen. The Abassíyyeh Observatory registered (1871) nine rainy days at Cairo, with a total of 9.08 hours; and thus it gave a rain-fall inferior to that witnessed by the beginning of the century."*

Similar statements have been made repeatedly in regard to changes of climate in Salt Lake Valley, Utah, said to have been brought about by the cultivation of tracts bordering on and in the vicinity of that lake. Mr. Hough,† after describing the irrigation works in Utah, which had, as he says,

* R. F. Burton. The Gold Mines of Midian. London, 1878, p. 26.

† In the Report to Congress on the Cultivation of Timber, etc., already quoted, p. 92.

extended over 127,798 acres (somewhat less than one four-hundredth part of the whole area of that Territory), says: "All observers agree that the climate is improving under the increasing breadth of vegetation which this system of cultivation has created. . . . . The industrious Mormons have a right to expect that, as the breadth of cultivation extends, the rains will increase in the same ratio; that the air will become more humid as trees are planted, and that a self-sustaining amount of rain-fall may in time be obtained." It is not denied that Great Salt Lake began to rise about the year 1866, and continued to do so for several years after that time. This confirms the thoroughly well authorized deductions drawn from a variety of facts observed all through the Great Basin, namely, that the desiccation of the region has not been absolutely uniform in character; but that, on the other hand, it has proceeded with more or less gentle oscillations, the result of which, on the whole, has been, that the lake now stands several hundred feet lower than it has done since there has been any orographic change in the region.* We shall have abundant occasion, farther on, to point out facts indicating, in the most unmistakable manner, that the forces regulating evaporation on the earth are so delicately balanced that fluctuations of these, too small to be registered with our ordinary instruments, produce results which are decidedly well-marked in their effect on climate. But these fluctuations, such as those of the Great Basin Lakes within the past few years, do not interfere with the general result, which slowly but surely maintains itself in spite of them.

The reason why Salt Lake has, on the whole, greatly diminished in area within the recent geological period is, that evaporation more than counterbalances the precipitation. This rain-fall in the valley of Salt Lake itself is large, as compared with that of places in the adjacent region,† owing, no doubt, in part to the existence in the immediate vicinity of so large a body of water, covering, as it does, an area of about 2,400 square miles. The cultivation and partial irrigation of less than 200 square miles of surface could not, under the most favorable hypothesis, add materially to the effect produced by an unbroken body of water twelve times as large immediately adjacent.

The water used for irrigation in Salt Lake Valley comes from the summits

* See *ante*, p. 103.

† The rain-fall at Great Salt Lake station, as given by the Smithsonian observer, is about four times that at Fort Bridger, about seventy-five miles distant in an easterly direction.

of the adjacent mountains, and chiefly from the melting of the snow deposited on these during the winter. This snow is the result of the condensation of moisture in the air brought from a great distance — perhaps even from the Pacific Ocean — by the prevailing westerly winds. It is as unphilosophical to take it for granted that the climate of Utah could be essentially altered by the irrigation of a hundred or two of square miles, as to suppose that planting trees on the meadows of the Connecticut River, between Springfield and Northampton, would have a perceptible influence on the distribution of rain in Massachusetts.

That the temporary rise of Great Salt Lake had nothing to do with the cultivation of a minute portion of the adjacent region is sufficiently proved by the fact that Winnemucca and Pyramid Lakes were at the same time rising, and in an equally rapid ratio with Great Salt Lake.* But during this very period of their most rapid increase, and for some years previous to it, the adjacent regions in California and Nevada were being stripped of their trees with the greatest rapidity. There is just as much reason for inferring that the rise of Winnemucca and Pyramid Lakes was produced by disforesting the country, as that the similar increase of Great Salt Lake was the result of tree-planting by the Mormons; in other words, there is no truth in either statement.

It is a favorite idea with people living in the Mississippi Valley, who cannot bear to admit that their country can, by any possibility, be deficient in any of the good things of this world, that the treeless condition of certain portions of their fertile territory has been artificially produced. It is thought that forests once covered the prairies, and that the Indian aborigines have burned them off. This must have happened before the settlement of the country by the whites, since the very earliest European travellers — Hennepin, for instance — describe the prairies just as we see them now. It is not necessary to enter into an argument to refute so absurd a theory. Those who advocate it can have no eye for nature, and no experience in the study of problems of physical geography. It is only referred to in this connection for the purpose of proving the almost self-evident fact that absence of forest vegetation does not necessarily prevent a country from being rich, prosperous, and able to support a dense population. The State of Illinois, for instance, may be properly set down as almost wholly a "prairie country,"

* Mr. King states (Geology of the Fortieth Parallel, Vol. I. p. 506) that between 1867 and 1871 the area of Winnemucca Lake had nearly doubled.

for "timber" occupies but a very small proportion of its area; but it would not be easy to find any part of the earth's surface of the exalted value of which its inhabitants have a higher opinion. If the country has been rendered treeless by human hands, it has not, in the process, been in the slightest degree reduced "to the commercial and social level of the disforested countries of the Mediterranean." *

The consideration of this subject might be much prolonged, and a large amount of additional evidence brought forward, showing that there is, in many places, an abundant precipitation on regions quite destitute of trees. At present, however, no more need be said on this point. Farther on, it will be advisable, after having discussed the nature of the causes influencing precipitation, both in amount and distribution, on the earth, to recur to the subject of the treeless regions about the Mediterranean, and to explain why the climate there is what it is. At present only a few words may be added in regard to influence of forests on climate, and their connection with the welfare of the people.

Forests may cover a country so densely as to be a heavy drawback to its settlement and cultivation; as, for instance, is the case over a large area in Washington Territory and Oregon. Forests may even be a terrible curse to the inhabitants, where they exist in too great abundance, as the experience of the settlers in parts of Michigan and Wisconsin has, within the past few years, repeatedly and most lamentably shown. A country too thickly timbered is not capable of cultivation, neither is it a healthy one. Every new and densely forested country must, therefore, go through a preliminary course of having its trees cut down, and replaced by a second growth, suitable to the wants and conditions of the inhabitants. Of course while this is being done "lumber" is both abundant and cheap, and as the forests are gradually removed it becomes dearer; this, however, by no means implies ruin. That the supply of timber in many regions is drawn upon faster than it need be, and that it is often recklessly wasted, is not to be denied. It is the custom of mankind to waste that which nature has supplied to them in the greatest profusion. Such waste is a part of a general system of unthrift; but there is nothing necessarily more alarming in wasting forests than in wasting soil, or other good gifts of Providence.

In nature there is every grade of tree productiveness, according as the combined conditions of soil and climate vary. We may have regions, like

* See *ante*, p. 163.

those of the tropics, where it is with the greatest difficulty that forests can be kept from encroaching on the clearings; or we may have those, like the Great Basin, where arboreal vegetation hardly exists at all, and where what little does exist is with difficulty replaced when it has once been removed. Countries in the latter category are, of course, those where the precipitation is already very small and still diminishing. In such cases we may easily conceive that the existing scanty forest represents a past condition of things rather than the present one.

That where the conditions are as thus indicated the question of preserving the still remaining forest growth may become one of some importance cannot be denied. Just as a man in the desert with only a scanty supply of water would husband it by putting it in the shade, rather than allow it to be exposed to evaporation in the direct sunlight, so we may suppose that the total disappearance of springs may be retarded in a desiccating country by carefully preserving the forests which still cling to the shady nooks and recesses of the mountains. That the total amount of precipitation might thus be increased in any perceptible degree is not at all probable; it is simply a method of economizing that which does fall, and as such might be of importance. It is also generally conceded that in very dry countries the small rain-fall which does occur is liable to come in the most irregular manner, and there is a strong disposition to ascribe this to the absence of forests. Inasmuch as very dry countries are usually treeless, the association of irregularity of rain-fall with absence of forests is a very natural one; but, as has already been seen, treeless regions may be abundantly watered, and then precipitation has its usual regular course. The astonishing amount of water which can be precipitated, within a short space of time, in a region where the total average rain-fall is very small, and where the country generally has the aspect of entire dryness, is something wonderful to behold. Such violent falls of rain are popularly known in the Cordilleras as "cloud-bursts." Of course any one such phenomenon is limited to small areas; but if it takes place where the topographical conditions are favorable, so that the waters are confined in their course, persons may be and have been — to the writer's knowledge, in more than one case — drowned on a spot where but a few minutes before all was absolute dryness. The nature and cause of these cloud-bursts seems to be but imperfectly understood; but the constant association of intense electrical displays with them would seem to indicate a causal connection between the two sets of phenomena.

Of the importance of a covering of vegetation, either grassy or arboreal, in protecting the soil from being washed away by violent rains, especially and chiefly on steep mountain slopes, nothing need here be said, for the subject is well understood and extensively acted on in practice. But forests as regulators of the flow of the excess of precipitation over any given surface, and forests as causes of that precipitation, are two very different matters.

A few words may here be added in reference to a point already suggested,* namely, an assumed antagonism between man and nature, in consequence of which, all nations, after having reached an advanced stage of development, must sink into decay, a certain destructiveness, or hostile influence, inherent in the race, gradually rendering the earth unfit for habitation, and thus bringing about the downfall of that prosperity to the permanent continuance of which the physical conditions had become unsuited.

Precisely in what this hostile influence consists it is not so easy to make out. Perhaps its nature may be inferred, to some extent, from the following quotations from a popular work which is largely devoted to an elucidation of the conflict between man and nature: † "Man has too long forgotten that the earth was given to him for usufruct alone, not for consumption, still less for profligate waste. Nature has provided against the absolute destruction of any of her elementary matter, the raw material of her works; the thunderbolt and the tornado, the most convulsive throes of even the volcano and the earthquake, being only phenomena of decomposition and recomposition. But she has left it within the power of man irreparably to derange the combinations of inorganic matter and of organic life, which through the night of æons she has been proportioning and balancing, to prepare the earth for his habitation, when in the fulness of time his Creator should call him forth to enter into its possession. . . . . But man is everywhere a disturbing agent. Wherever he plants his foot, the harmonies of nature are turned to discords. The proportions and accommodations which insured the stability of existing arrangements are overthrown. Indigenous vegetable and animal species are extirpated and supplanted by others of foreign origin, spontaneous production is forbidden or restricted, and the face of the earth is either laid bare or covered with a new and reluctant growth of vegetable forms, and with alien tribes of animal life. These intentional changes and substi-

* See *ante*, p. 164.

† The Earth as Modified by Human Action. By George P. Marsh. A New and Revised Edition. New York. 1877.

tutions constitute, indeed, great revolutions; but vast as is their magnitude and importance, they are, as we shall see, insignificant in comparison with the contingent and unsought results which have flowed from them. . . . . In short, without man, lower animal and spontaneous vegetable life would have been practically constant in type, distribution, and proportion, and the physical geography of the earth would have remained undisturbed for indefinite periods, and been subject to revolution only from slow development, from possible, unknown cosmical causes, or from geological action. . . . . There are parts of Asia Minor, of Northern Africa, of Greece, and even of Alpine Europe, where the operation of causes set in action by man has brought the face of the earth to a desolation almost as complete as that of the moon; and though, within that brief space of time which we call 'the historical period,' they are known to have been covered with luxuriant woods, verdant pastures, and fertile meadows, they are now too far deteriorated to be reclaimable by man, nor can they again become fitted for human use, except through great geological changes, or other mysterious influences or agencies of which we have no present knowledge, and over which we have no prospective control. The earth is fast becoming an unfit home for its noblest inhabitant, and another era of equal human crime and human improvidence, and of like duration with that through which traces of that crime and that improvidence extend, would reduce it to such a condition of impoverished productiveness, of shattered surface, of climatic excess, as to threaten the depravation, barbarism, and perhaps even extinction of the species." *

The above quotation has been extended to considerable length, partly because it seemed necessary to do so in order that the author's ideas might be fairly displayed, and partly, also, because the work from which the extract has been made is one which has passed through several editions,† and which is generally considered to be of high authority. It is not easy to make out exactly in what really consists this assumed destructive influence of man, the alarming consequences of which are so vividly depicted in the volume in question. A perusal of the whole work gives the strong impression that by far the most important agency in the business is the cutting down of the forests, the disastrous effect of which on climate, as maintained by so many writers, has already been so fully set forth and commented on in the pre-

* l. c., pp. 34 - 44, *passim*.

† It has also been translated and republished in Europe, with marked approval.

ceding pages. One more quotation from the same work will, at all events, show that its author is most profoundly impressed with the reality of the dire results sure to follow the clearing of the woodlands: "When the forest is gone, the great reservoir of moisture stored up in its vegetable mould is evaporated, and returns only in deluges of rain to wash away the parched dust into which that mould has been converted. The well-wooded and humid hills are turned to ridges of dry rock, which encumbers the low grounds and chokes the water-courses with its débris, and — except in countries favored with an equable distribution of rain through the seasons, and a moderate and regular inclination of the surface — the whole earth, unless rescued by human art from the physical degradation to which it tends, becomes an assemblage of bald mountains, of barren, turfless hills, and of swampy and malarious plains." *

Enough has already been said in regard to the supposed effect on climate of the removal of the forests. All that need be added, at the present time, is simply to call attention to the assertion quoted above, that Asia Minor, Northern Africa, and Greece are known "within the historic period to have been covered with luxuriant forests." This is a statement which cannot be substantiated by proofs, as has already been remarked.† But, even if it could be shown that the region in question was once densely covered by forests, it would still remain to be proved that their removal had brought about the change in the climate and other unfavorable conditions so graphically depicted by the author from whose work the above quotation has been taken.

Barrenness resulting from over-irrigation and exhaustion of the soil by cultivation are also cited by various investigators into this class of problems as among the prominent pernicious effects produced by the agency of man. That the idea of injury to a country by over-irrigation should have taken root in the minds of some is by no means difficult to understand. A region in need of irrigation is one of scanty rain-fall, and of course of excessive

* l. c., p. 43.

† Theobald Fischer, who has devoted much time to an investigation of the climatic conditions of the countries bordering on the Mediterranean, admits that the region in question has become drier since the historic period. Although inclined to consider a part of the mischief as the result of man's interference with nature, he is obliged to admit that this desiccation cannot be accounted for without calling in the aid of some more general and potent cause, the nature of which, however, he does not suggest. This author also remarks that the climate of Greece was already a dry one in classical times, and he brings no evidence that this country was then covered, to any extent, with forests. (See Theobald Fischer, Studien über das Klima der Mittelmeerländer, in Ergänzungsheft to Petermann's Mittheilungen, No. 58, pp. 41–46.)

evaporation. The water used for irrigation, under such circumstances, as it evaporates leaves behind the saline matter with which it is charged, which thus accumulates so that the soil in time becomes too strongly impregnated with it to admit of successful cultivation. This is only one of the manifestations of increasing desiccation. It is an example of the difficulties which man meets in his struggles against unfavorable physical conditions, and a proof of his inability to overcome them.

The subject of the exhaustion of the soil, by constant cultivation without restoring to the ground that which has been removed by the growing crops, is one of great importance, but too remotely connected with the topics under discussion in the present volume to make it necessary to examine it in detail. Using up the resources of a country by relentlessly drawing from the soil the available elements with which it is stored has, at all events, nothing to do with desiccation, and can only be put in the same category with the destruction of forests, on the ground that both operations indicate unthrift and wastefulness. A country which is not sufficiently supplied with moisture cannot be successfully cultivated; hence those who consider dryness to have been produced by the hand of man will also naturally ascribe the barrenness resulting from desiccation to the same cause. It would be no more reasonable to ascribe the dryness of the lands bordering the Mediterranean to cultivation, than it would be to maintain that the climate of Nevada had been deteriorated by the rapid working out of its silver-mines. The trees in a region sufficiently supplied with moisture will, after having been cut down, be soon replaced by others. In a country where desiccation has advanced so far as it has over a large part of Asia Minor, Greece, and Northern Africa, the forest-growth, if removed, is only with great difficulty, or not at all, replaced. In this respect the trees in a dry country are like the ore in a mine, which is there once for all, and, having been worked out, is gone forever. The inability of the ore to reproduce itself and of the forest to grow again are both the results of natural causes; the difference being that, in the case of the ore, this would remain forever in the ground unchanged in quality, if not touched by the miner, while the forest would surely, if left to itself, decay away and perish, however religiously it might have been spared by the hand of man.

Everything in the world's history shows that nations have preferred to change their place rather than to attempt to battle against nature. Civilization has pushed its way from the southeast towards the northwest, on the great continental mass of Eurasia, leaving the interior desiccating regions for the shores blown upon by the return trade-winds, carrying with them the moisture necessary to comfort and welfare. The proportion of the earth's surface which, at any one epoch, presents exactly those conditions necessary for the development of a dominating and progressive race, appears to be quite limited. A temperate climate, sufficiently supplied with moisture, is a *sine qua non* of intellectual development; but such is not to be created by man himself, nor can the deterioration wrought by nature be artificially removed or postponed in any but the most limited degree.

Leaving for the present the question of precipitation as connected with the power of man to increase or regulate it, we pass to the consideration of another topic, namely, the phenomena of desiccation as indicating an epoch during which the earth is recovering — so to speak — from the effects of a previous condition of glaciation.

SECTION III. — *Desiccation as a Phase of the Glacial Epoch.*

From what has been stated in the preceding section it will appear evident that the popular view of the phenomena of desiccation is, that they are the result of man's interference with the course of nature. This theory is not only the favorite one with the people, but it has been extensively advocated by physical geographers; that is, by the class of investigators which limits its studies of the earth's surface to the consideration of its present aspect, without having any special idea of connecting that present with a series of precedent conditions. In extending our scientific inquiries, and endeavoring to trace back the phenomena of the present into a distant past, and to establish a relationship between what is now happening and what did happen during preceding ages, we enter the domain of geology.

Geologists, as might naturally be expected, have not generally adopted the views set forth and controverted in the preceding pages in relation to the diminution of the water over certain portions of the earth. While not ignoring altogether the important facts which immediately present themselves when we come to study almost any part of the earth's surface with reference to the question before us, they have — so far, at least, as American geologists are concerned — almost without exception taken up a position which is, as the writer considers, far from satisfactory, since it neither enables them to account for past nor present climatic changes proved to have been taking place, nor to connect these facts into a sequence the progression of which indicates the constant action of cosmical agencies unbroken by interruptions and antagonisms, for which no probable cause can be assigned, and which are not in any degree in harmony with what, as we have abundant evidence to prove, did take place during the preceding geological periods.

The view generally taken by geologists of the phenomena of desiccation, so far as these are noticed at all, is, that they form a part of a series of events which took place during the so-called "Glacial epoch;" or, rather, that they are the necessary sequence of those events, and, so to speak, the "winding up" of that epoch.

The idea is, that at a certain period in the earth's history a refrigeration of our planet caused the precipitation of certain regions to take the form of snow exclusively, which being converted into ice became accumulated upon the surface, and was thus laid away for use in future ages, just as the snow-fall of the winter in high mountain regions, at the present time, furnishes a supply of moisture by its melting during the succeeding summer. According to this view all indications of a former larger amount of moisture in any particular region are referred, at once and without doubt, to the melting of the "great glacier." If a lacustrine area exhibit signs of having diminished, it is because it was once larger, owing to the increased supply of water to it during the melting of the ice of the Glacial period. So with regard to all the other evidences of a larger amount of water carried off the surface in various regions, such as is afforded by terraces and the like; this is all referred to the conclusion of the Glacial epoch, and considered as a natural result of a more or less sudden melting of a great mass of snow and ice previously stored away in the form of the "great ice-sheet."

To illustrate the nature of this view, a few quotations may be introduced from recent writers on this branch of geology. Mr. H. C Lewis, after describing the extensive deposits of rolled gravel of the valley of the Delaware, and calling attention to the fact that the amount of water must once have been much larger than it now is, says: "It is difficult to imagine an origin for such a flood as we have described other than the melting of a glacier. We have shown that the flood was not an inroad from the sea, but that it came down the valley. No rain-storms of modern experience could have supplied such a flood. To call the time of this flood a 'Pluvial Epoch' will be of little assistance, since no origin for such extraordinary rains is suggested, except under a very different climate, or by evaporation from a melting glacier." * In this statement it is in reality assumed that a larger supply of water than that now flowing in our rivers could not be occasioned in any other way than by the melting of ice. This is equivalent to taking the position that there can be no changes of climate except such as are registered in the accumulation and subsequent thawing of ice-masses.

Professor N. H. Winchell, in speaking of the effects resulting from the dissolution of the great glacier, which he had previously described as having been spread over the whole northern portion of North America, indicates the phenomena which would follow the melting of the ice in these words: "The turbid streams would be vastly larger than those which occupy the same beds to-day. They would run with tenfold more violence." †

According to the same author, terraces are due solely to floods along the rivers and lakes, consequent on the melting of the "great glacier."

Mr. S. F. Emmons, in indicating the magnitude of the erosion which has taken place in the Green River basin since Pliocene times, says: "The bulk of this material must have been carried away by the floods which followed the Glacial period, while at the present day, under conditions of comparatively slight precipitation, the amount removed from the basin region by the actual agency of water is relatively slight." ‡

Mr. G. K. Gilbert, in his description of the former condition of things in Great Salt Lake Valley, § alluding to the once greatly enlarged area of that lake, says: "There can be no doubt, then, that the great climatal revolution, which covered our northeastern States with ice, was competent to flood the dry basin of Utah; and that it actually did so is highly probable." ||

From the last paragraph we see that it was the opinion of the author quoted that the Salt Lake region had been an arid one previous to the Glacial epoch, and that synchronously with this, and under the action of the same causes, the lake became greatly extended in area. According to Mr. Emmons's views, as will be perceived, it is the entire Glacial epoch which is the period of greater precipitation, and its cessation, simply, which is the cause of desiccation.

* The Trenton Gravel, and its Relation to the Antiquity of Man. By Henry Carvill Lewis. From the Proceedings of the Academy of Natural Sciences of Philadelphia. A paper read Nov. 24, 1879.

† The Drift-Deposits of the Northwest. Popular Science Monthly for June and July, 1873.

‡ Fortieth Parallel Survey Report, Vol. II. p. 206.

§ See *ante*, p. 106.

|| United States Engineer Reports of Explorations, etc., west of the 100th Meridian, Vol. III. p. 96.

Professor R. D. Irving, of the Wisconsin Geological Survey of 1873–77, thus succinctly states his views in regard to the Glacial period and a subsequent period of inundations: "The stratified drift of the valleys owes its structure and distribution to the water of the swollen streams and lakes that marked the time of melting of the glaciers."* Professor T. C. Chamberlin, chief of the same survey, holds a similar opinion, as is clearly to be gathered from the following quotation from his report: "The melting of the ice-mass gave rise to swollen lakes and flooded rivers, which eroded at some points and filled up at others, and so still farther modified the face of the country."†

Professor N. S. Shaler, former Director of the Kentucky Geological Survey, in speaking of certain deposits of blue clay occurring in the terraces of the Ohio Valley, says: "I am inclined to think that it was formed at the time the valley was swept by the floods, which came during and at the close of the glacial period, when, for a great length of time, this valley was the seat of a far more powerful stream than at present."‡

Professor C. H. Hitchcock, Director of the New Hampshire (Second) Geological Survey, says, in describing the terraces occurring along the Merrimac and Connecticut Rivers: "We conclude that at the close of the glacial period, when the ice was melting rapidly, the rivers filled their valleys even with the tops of the highest terraces."§

Quotations enough have been given to show that American geologists concur very generally in looking upon the close of the Glacial period as a time of great floods, and an abundance of water running and standing upon the surface, all coming from the melting of the "great glacier." It will be proper, however, to add the very clear and emphatic testimony to this effect offered by Professor Dana, in his text-book, which is, and very properly, in the hands of all professional geologists and of most advanced students of the science throughout this country, and which reflects very closely the general opinion held here in regard to geological "questions of the day." He says, after describing "the glacier of the Northern Hemisphere," || under the head of "The Final Flood from the melting of the Glacier": "That the melting of the glacier should have ended in a great flood may be inferred from the

* Geology of Wisconsin. Survey of 1873–77, Vol. II. p. 635.

† l. c., p. 98.

‡ Geological Survey of Kentucky. New Series, Vol. III. Part III. p. 75.

§ The Geology of New Hampshire. Concord, 1874, Vol. I. p. 542.

|| Manual of Geology. Third Edition. New York, 1880, p. 555.

common observation that in cold latitudes floods terminate ordinary snowy winters. The subsidence of northern lands would have brought on the conditions of a warmer climate; and, as the melting went slowly forward, this amelioration must finally have become very decided. Consequently, there was melting, not merely along the southern edge of the glacier, but over its wide surface; and, when the thickness of the ice was at last reduced to a few hundreds of feet, and it had become rotten throughout, the melting must have gone forward with greatly augmented rapidity; and a flood, filling rivers and lakes to an unwonted height, must inevitably have followed. The fact that such a flood, vast beyond conception, was the final event in the history of the glacier is apparent in the peculiar stratification of the flood-made deposits. . . . . Only under the rapid accumulation of immense amounts of sand and of gravel and of water from so unlimited a source, could such deposits have been accumulated."

Professor Dana is so profoundly impressed with the importance as a geological event of the melting of the "great glacier," that he makes of the time of its occurrence a distinct period in the Quaternary age, to which he gives the name of "Champlain," dividing this period into two epochs, the Diluvian, and the Alluvian. According to him, the earlier part of the Champlain period "was the era of the melting of the great glacier, and of most local glaciers; and therefore the era of immense floods along the valleys; of many and great lakes; and of the deposition of the sand and gravel of the glacier."* This early portion of the Champlain period constituted the "Diluvian epoch." The "Alluvian epoch," on the other hand, formed "that part of the era of depression, after the melting had ended, characterized by depositions of a more quiet character."

As it will be necessary, farther on, to refer again to these views of Professor Dana's, it is sufficient, at present, to point out that there is, in his Manual, no special reference to any cause of diminution of water-surface, on the globe, other than that implied in the above quotations, except in so far as reference is had to the building up of the continental masses, or the gain of the land upon the sea. The prominent facts with regard to the desiccation of large portions of the American and Asiatic continents, where no "great glacier" ever existed, have not been noticed by him.

On examining the works of European geologists, it is found that the idea of a moister climate as connected with the Glacial epoch, and a deluge of

* l. c., p. 543.

water as resulting from its sudden melting, has not taken as firm hold of them as it has on investigators in the same branch of science in this country. The reason why this is so will, as the writer believes, be understood without difficulty, after perusal of the following chapter, which has to do especially with glacial phenomena. That to some extent, however, views prevail there in regard to the diminution of moisture on the earth similar to those so generally held in this country will appear from the following quotations.

Mr. D. Mackintosh, in his work on the character and origin of the scenery of England and Wales, when discussing the subject of former increased fluviatile action, remarks as follows: "Mr. Prestwich and others, seeing the difficulty of explaining the breadth of many valleys by existing river-action, have had recourse to the theory that during the breaking up of the glacial conditions which once prevailed in the north-west of Europe, and the melting of ice and snow, the rivers must have acquired a great increase of volume and consequent breadth of excavating power." *

Mr. James Geikie adopts a similar view, and quotes the opinion of one of the eminent Swiss geologists in regard to the supposed connection of the Sahara with the Glacial epoch, a theory to which reference has already been made,† and which will be noticed again farther on, making the following remarks: "It would seem that during a comparatively recent period the desert of Sahara was submerged, recent marine shells having been found widely distributed over its surface [this statement has been shown by later researches, with which Mr. Geikie was not acquainted, to be incorrect, the marine deposits in question occupying but a very small portion of the vast area of the Sahara] and imbedded at some depth in the sand. It is highly probable that, as Escher von der Linth has suggested, this submerged condition of the Sahara obtained during the Glacial epoch, and that much of the moisture which then fed the great snow-fields of the Alps was brought by the prevalent winds flowing from Africa across the Sahara Sea and the Mediterranean." ‡

What remains to be done, in the present connection, is to show that connecting the observed phenomena of desiccation, as presented to the reader in the previous chapter, with the epoch of glaciation does not offer a satisfactory solution of the problem before us. How that epoch does connect

* The Scenery of England and Wales, its Character and Origin: London, 1869, p. 280.

† See *ante*, pp. 146 – 149.

‡ The Great Ice Age and its Relation to the Antiquity of Man. London, 1874, p. 402.

itself with those which preceded it, as well as with those by which it was followed, will be, to some extent, set forth in the next chapter. Before advancing another stage in our discussion, however, we have to make it clear that the diminution of the rivers, the disappearance of the lakes, and all the other phenomena indicative of a gradual but persistent tendency to aridity over vast areas once fertile and well watered, do not form a transient phase of a precedent Glacial epoch, but are the result of some cause which began to act before that period, and is still continuing without any connection with it.

To throw light on this matter we may again turn to the facts made evident in the course of the investigations of the gravel deposits of the Sierra Nevada, where, as the writer conceives, we find the series of geological events, in so far as they relate to the question now before us, so well marked that it is impossible to mistake their order of succession and their connection with each other. All the points to which attention should be turned, in reference to the diminution of the rivers of the Sierra, cannot be taken up at the present moment, but certain inferences of importance can be drawn. And, in the first place, it is certain that in the gravel region of California there is ample proof that the decrease in volume of the Tertiary rivers had been begun in Tertiary times, and carried so far that the changed condition of things, in this respect, had before the close of that epoch become a feature of the utmost importance in the climatology of that region. The whole character of the drainage channels had undergone a change, as described in the Auriferous Gravels;* broad streams, with gradually sloping banks, having given place to narrow ones, confined in deep gorges with extremely precipitous sides.

Indeed there seems to be little doubt that the topography of the western slope of the Sierra had received what may be said with truth to have been essentially its present form and character, before the epoch of the extension of the glaciers over that range took place. And, what is still more important in this connection, it admits of little doubt that hardly any perceptible change was effected in the topographical features of the range during the time when ice covered its summits, to the extent and in the manner described, in considerable detail, in the first chapter of the present volume. A similar statement may be made with truth in regard to the other ranges of the Cordilleras, over which glaciers spread themselves during the Cordil-

* See Auriferous Gravels, p. 335, and *passim*.

leran Glacial epoch. At least, this is the inference which the writer has been compelled to draw from his own observations, as well as from the study of the published works of other geologists. Everything indicates a great slackening of the erosive forces, and a gradual diminution in the quantity of water flowing over the surface during the later geological times, and that the glacial development through that whole region was neither the beginning nor the ending of this diminution. And there is every reason to believe that the melting of the Cordilleran glaciers did not cause floods which raised the rivers to anything like the magnitude they had had in Tertiary times, while there is no proof that this melting was attended with effects justifying, in any degree, our considering it as constituting an event of any great geological importance in that region.

But it may be said that what is true for the glacial period of the Cordilleras need not necessarily be so for the same epoch in other parts of the world. This may be admitted; and it may be added, that the time of the greatest extension of the ice over the Sierra Nevada may not have coincided with that of the development of the great ice-sheet in Eastern North America; or it may even be doubted whether the phenomena on the two sides of this continent were at all of the same order of magnitude. This, however, does not affect the question at issue. If the proved drying-up of the vast region of the Cordilleras constitutes a geological and climatological occurrence independent of the Glacial epoch, then, even granting all that Professor Dana claims, in regard to the importance of the melting glacier on the eastern side of the continent, this latter occurrence can only be considered as a local one, and evidently cannot be connected with a general desiccation going on over the whole earth, such as seems so plainly to be inferred from the facts set forth in the preceding chapter.

What has just been stated in reference to Western North America is still more forcibly impressed upon us by the conditions existing in Asia. Here phenomena similar to those occurring in our own country have been displaying themselves on a still grander scale than with us. Desiccation is the most marked climatological fact which there presents itself to us. It was begun at least as far back as early in the Tertiary epoch, and there seems to be little if any doubt that it has been prolonged into the historical period and is still going on. But Asia is a continent which has never had a "Glacial epoch," as will be set forth in a succeeding chapter. In no part of that vast continental mass has there ever been any essentially greater development of ice than there is at the present time. Hence the desiccation which has there gone on for so long, and which is still proceeding, can in no wise be connected with the melting of any glacier, or set of glaciers, or great general ice-sheet. It must be a phenomenon quite independent of the occurrence of the Glacial epoch. The same being, as already shown, true for a large part of North America, and, as far as the limited facts at our disposal allow of an opinion being formed, for Africa and South America, we are manifestly led to prosecute our inquiries in another direction, leaving the consideration of the Glacial epoch to one side for the present, as not leading us toward the solution of the problem before us.

Only one aspect of the prevailing theory in regard to the melting of the "great glacier" will be touched upon before proceeding to another branch of our inquiry. It is this: it is assumed that the time of the melting of large glaciers, and especially of an ice-sheet extending over a large area of country, must necessarily have been one of great floods. This view cannot, however, be accepted as being, *prima facie*, correct; certainly it needs some explanation and limitation. The question comes up, in the first place, whether a mass of ice may not disappear by evaporation, so that its melting away may be attended by no deluge of water. The vast quantities of snow piled up in the Sierra Nevada during the winter, as a rule, do disappear without producing great freshets. Such events as that of the flooding of the Sacramento Valley in 1861–62 do not proceed from any ordinary melting of the winter's snow under the influence of a summer sun; they are produced by a deluge of warm rain suddenly precipitated upon a body of snow which has just fallen in the Lower Sierra, and which has not had time to become carried away in the ordinary manner by evaporation. Such very sudden changes in the temperature of the air, or rather in the direction of the air-currents, can be understood as a phenomenon of local occurrence; but it would not be easy to imagine a large part of a continent as being subjected instantaneously, as it were, to such a climatic change.

As an illustration of what is here meant to be stated, attention may be called to the fact to which much fuller reference will be made in the next chapter, namely, that the glaciers of the Pyrenees, the Alps, and the Caucasus have, for the last thirty or forty years, been in process of diminution; they have in fact been disappearing so rapidly that, should this shrinking be continued at the present rate for one or two hundred years longer, there will hardly be any ice left on the Alpine summits. It does not appear, however, that this decrease of the ice-masses has been attended with any of those floods which we are told by geologists must have been synchronous with the melting of the great glacier. On the contrary, complaints, not unsupported by statistical data, have been going on all this time that the rivers fed by this region of disappearing glaciers were themselves, if not disappearing, at least diminishing in volume.

Much more might be added in illustration of the position here taken, that the diminution of the lakes and rivers and the general drying-up of the earth, described in the preceding sections of this chapter, are not to be explained by a simple reference to the melting of a "great glacier." But it is thought that, if enough has not already been said on this subject, the next chapter will furnish sufficient additional matter in refutation of this idea, shown to be so commonly held by geologists, — at least in this country, — and that we may now proceed with the discussion of the subject of desiccation, with a willingness on the part of our readers to hear what there is to be said in regard to causes of climatic change far more general in their action and important in the results they have brought about than any implied in the melting of the ice over certain areas of very limited extent compared with the entire land-surface of the globe.

SECTION IV. — *Examination of the Conditions favoring, or tending to diminish, Precipitation upon the Earth's Surface.*

As a preparation for what is to follow in this chapter and the succeeding one, it will be desirable, at the present stage of this discussion, to consider — although necessarily in a somewhat brief manner — the causes influencing precipitation on the earth's surface, both as to its entire quantity, and the manner in which it is locally distributed, whether in the form of rain or snow. What is now to be said will also have a bearing on, and be an assistance to, the understanding of portions of that which has been already set forth in the preceding pages of this volume.

Precipitation is the indirect result of evaporation, and the amount of water which falls as rain or snow is entirely dependent on that taken up from the surface of running or standing water by the agency of the sun's heat. From all moist surfaces evaporation is continually abstracting the water, but with very different degrees of rapidity according to varying conditions. The principal agent accelerating evaporation is increase of temperature. "By the increase of temperature the elastic force of the vapour in the atmosphere is increased, and with it the rate of evaporation." * Hence, as a general rule, the warmer regions of the earth are the areas over which precipitation is greatest. No one can doubt for a moment that a diminution of the mean temperature of the earth's surface, other conditions remaining the same, would bring about a diminution in the total quantity of rain and snow precipitated. This self-evident fact is to be kept in mind during the present discussion, since it forms, so to speak, the basis on which the present chapter rests.

It needs, however, but little experience in the study of physical geography and meteorology, or but a slight examination of the rain-charts of the world, to convince the inquirer into this subject that the distribution of rain-fall on the earth's surface is extremely irregular and — as it would, perhaps, at first sight appear — even capricious. While the tropical regions, on the whole, receive a very heavy precipitation, certain countries where the mean temperature is very high are included within the almost or quite rainless areas, while other regions, in high northern latitudes, where we know that the mean temperature must be quite low, are abundantly supplied either with rain or snow, or with both. We must therefore proceed to investigate what other cause or causes influence precipitation on the earth's surface as a whole, and then pass on to inquire what are the conditions by which its distribution over various regions is mainly influenced.

Evaporation takes place from the surface of water, from moist surfaces generally, and even from snow and ice. But the essential point is this: that with a given temperature the larger the surface of the water exposed to the atmosphere, other conditions being equal, the larger the amount of moisture which will be taken up, while the quantity precipitated will, somewhere on the earth's surface, be proportionately increased.

For reasons, the ultimate cause of which we are quite unable to fathom, we find the solid crust of the globe to be covered, to a large extent, with water,† holding in solution a considerable quantity (about three and a half

* A. Buchan, in "Handy Book of Meteorology." Second edition. Edinburgh and London, 1868, p. 148.

† The ordinary statement of the ratio of the surface of the land to that of the water on the globe, at the present time, is — in round numbers — four to eleven, the land occupying a little more than one fourth of the earth's surface. Behm and Wagner promise (in Ergänzungsheft, No. 62, to Petermann's Mittheilungen, 1880) a complete revision of their former figures, relating to the areas of land and water surface on the globe; but, so far as known to the writer, these results have not yet appeared. The figures given by Krümmel, in his "Versuch einer Morphologie der Meeresräume," are declared by them to be incorrect. Krümmel made the entire ocean surface equal to 366,506,106 square kilometers, or about 141½ million square miles.

per cent by weight) of certain substances, which remain behind in a solid form when the water is evaporated to entire dryness. The number of the elements which have been detected in the ocean is very large (somewhat over fifty have been already proved to thus exist); but much the larger portion of the material in solution in the ocean-water is made up of a few combinations which are abundantly distributed through the earth's crust, and at the same time extremely soluble. Of these common salt is by far the largest in amount and the most important. These soluble combinations are taken up by the water everywhere circulating through the superficial layers of the earth, go with this water wherever it finds its way, and finally reach the ocean, where they remain, as in a permanent reservoir, for an indefinite period. It is only when peculiar conditions isolate a portion of the ocean surface from the rest, and this portion becomes evaporated, that the saline substances resume the solid form. This operation has taken place on a grand scale in former geological ages, as is testified to by the existence, in various countries, of deposits of salt several thousand feet in thickness. The fact that the percentage and nature of the substances held in solution in the ocean is everywhere very nearly the same, is certain proof that the mixing process has been going on for an immense length of time. Of course this uniformity of composition refers to water taken at some distance from the land, where not influenced by the immediate presence of river-water.

The amount of surface on the earth occupied by water flowing in rivers, or standing as lakes, is by no means inconsiderable as compared with the area of the land, but almost insignificant when contrasted with the vast expanse of the combined oceans. The ocean, then, is the great reservoir from which the moisture to be precipitated upon the earth in the form of snow or rain is necessarily drawn. The larger the area occupied by the ocean, therefore, other conditions remaining the same, the larger on the whole will be the precipitation. The sun's heat becoming more intense, and the area of the ocean being at the same time enlarged, we have a double reason for an increase of the rain-fall; with a reversal of these conditions, on the other hand, we are warranted in expecting results of an opposite character; while an increase of temperature accompanied by a diminution of ocean surface would be a combination of conditions more or less neutralizing each other, the part contributed by each to the general result being perhaps extremely difficult to make out.

That the relative area of land and ocean surface is an element of the utmost importance in its relations to the entire precipitation of the earth will be readily admitted, although it would probably be difficult to give a numerical form to the result which, as we know, must necessarily follow any variation of this relation. So too it is plain enough that the distribution of rain and snow is largely dependent on the size and relative position of the land masses. An examination of any good rain-chart of the world will show this at once; and it will not require much study to enable the inquirer to perceive that there must be other important conditions which are influential in bringing about that irregularity in the precipitation to which reference has already been made. In fact, it is apparent enough that the distribution of the rain-fall, or the manner in which the evaporated moisture is caused to return to the earth's surface, is dependent on quite a complex series of conditions.

To condense the moisture of the atmosphere, so that it may fall as rain or snow, cold is required. Bodies of air must be in some way cooled down below the temperature necessary to enable them to retain, in the form of vapor, the moisture with which they are charged. This cooling is effected by the lifting up of the moist warm air into the upper, colder regions, which ordinarily happens in one or the other of two different ways: either currents moving in opposite directions come in conflict with each other and the mass of air is forced upwards, aided by the ascensional power given by added heat; or, on the other hand, a stratum of moving air impinges against a mountain slope, and is thus mechanically forced upward, until it becomes cooled to a sufficient degree, and lets fall the moisture with which it is charged.

The ordinary succession of events in the tropical belt of calms, or the region in which the conflicting currents of the trade-winds meet and neutralize each other, illustrates perfectly the manner in which precipitation is brought about in the equatorial region, in a way which is hardly at all dependent on the form or even the existence of land areas. It is especially over the broad expanse of the Pacific that we see in perfection what may be called the normal tropical rain-fall, the phenomena of which are so well known as not to require description. This belt of constant rains is, however, of no great width, and it moves with the sun across the equator; so that, on its extreme northern and southern limits, there is only one rainy and one dry season in each year, while, in the intermediate portions of the belt, there are two alternations of dry and wet weather.

As long as the trade-winds are blowing in their normal course, and before they reach the line where their progress is checked by meeting with the current coming from the opposite direction, they are necessarily dry winds, because they are blowing toward a region of higher temperature, and thus have their capacity for holding moisture increased. This is a point of the greatest importance, not only with reference to the distribution of the rain-fall on the ocean surface, but also on that of the land, as will be more fully noticed farther on, the precipitation on the continental masses being the matter with which we are especially concerned in the present inquiry.

An inspection of a rain-chart of the earth will show at once how distinctly marked are the areas of small precipitation on each side of the equatorial belt of continuous precipitation. This is especially conspicuous on the ocean, and particularly on the Pacific, where we naturally find the phenomena of normal rain-fall, independent of the effect of the land masses, best displayed. To quote from an excellent authority in this branch of meteorological inquiry, A. Wojeikof: "An understanding of the nature of the trade-winds shows us at once the necessity of admitting the existence of zones of rainless trade-winds, for these are winds constantly blowing from colder to warmer regions; that is, away from the point of saturation. Therefore, in oceanic regions, where the trade-wind blows steadily the whole year through, there can be no precipitation." *

From the rainless trade-wind belts, going north or south, we meet next with the regions over which the rain-fall has a character intermediate between that of the tropical rain-belt and that of the temperate zones. These sub-tropical zones of precipitation are somewhat marked features on the ocean; but in reference to the object of the present inquiry they are of comparatively small importance.

Beyond the sub-tropical rain-belts we have the temperate and polar

* See A. Wojeikof, Die atmosphärische Circulation. Verbreitung des Luftdruckes, der Winde und der Regen auf der Oberfläche der Erde. Ergänzungsheft, No. 38, to Petermann's Mittheilungen, 1874. The rain-chart accompanying this valuable memoir may be referred to in connection with what is said in the present section in regard to the rain-fall of the earth. So also may that which accompanies Professor Loomis's "Contribution to Meteorology," No. 16, in the American Journal of Science for January, 1882 ([3] XXIII. 1). The latter, however, has on it only the distribution of the rain-fall upon the land, while Wojeikof's map gives it for the entire surface of the earth. Professor Loomis's paper bristles with facts; that of Wojeikof, on the other hand, has more the character of a theoretical *résumé* of this department of meteorology. In view of the existence of these valuable papers, it is not necessary for the present writer to dwell on the subject of the causes influencing the distribution of precipitation on the earth. The main object of the present section is to impress on the mind of the reader the simplicity of the causes which influence precipitation in general as to quantity, and the complexity of the conditions which determine its local distribution.

regions, over which precipitation no longer has any features of regularity, but may be expected at any season of the year. These regions are the areas of constant rains, so called. As to the way in which precipitation would take place over the temperate and polar regions if the earth were entirely covered by water, it is not easy to form a precise idea. That it would be moderate in amount, as compared with that of the tropical regions, there can be no doubt, and that it would be distributed over the year, and not limited to one season, is also clear; moreover, there is every reason to believe that it would not be concentrated over special districts, leaving others nearly rainless, as is the case at present. Exactly how much variation there would be in the rain-fall, as we approached the immediate vicinity of the pole, it is not easy to say; but that there would be considerable increase in the amount it is reasonable to assume, as will be explained farther on.

In point of fact, what would be the normal distribution of precipitation if the earth's surface were entirely covered by water is entirely changed in character by the land masses, which produce this effect by their form and size, as well as by the manner in which the lowlands, the plateaus, and the mountain ranges which make up the continents are situated with respect to the oceans and to each other.

Statistical tables of the rain-fall of various stations throughout the world show that outside of the tropics the regions where the precipitation is large are very limited in area and peculiarly arranged with reference to the land masses; to this statement may also be added another, — which, in fact, is almost a corollary of the other, — to the effect that the areas of small rain-fall are very large, and evidently closely dependent for their position on the form and size of the continents. An inspection of the rain-chart* will illustrate these assertions better than can be done in words. Some explanation of these peculiarities may be here permitted, since the subject of the

* On Wojeikof's rain-chart of the earth the areas where the precipitation exceeds 1,200 millimeters (a little over forty-seven inches) are designated by fine lines. The regions thus indicated occupy but a very small space outside of the tropics. In North America, for instance, there is a belt along the coast of the United States extending north as far as Chesapeake Bay; another in the Mississippi Valley reaching not quite to the southern edge of Lake Michigan (including the prairie region, often considered as treeless on account of deficiency of moisture); and finally, another very narrow strip along the Pacific Coast, extending from the northern edge of California north to the parallel of 60°. In South America there is only a small area in the Brazilian Coast Mountains, reaching no farther south than the parallel of 30°; and another narrow belt on the southwest side of the southern end of Chili and along the coast of Patagonia. In Asia the smallness of the area of even moderately large precipitation outside of the tropics is still more striking, since only a part of China, along the valley of the Yang-tze, and the southeastern side of the Japanese Islands, is thus designated.

distribution of the rain-fall with reference to the form of the land masses is one of so much importance from a climatic point of view.

Every large continental area, not situated within the tropics, by its existence not only diminishes the entire precipitation on the earth's surface, in that it diminishes the area of the ocean, but it must also in its interior portion be the recipient of less than the average amount; and if the mass of land be large enough its interior will be reduced to the condition of an almost rainless country. This is the case with Asia, and to a very considerable degree with North America, in both of which continents there are very large areas where the precipitation falls below ten inches. The edges of the land masses receive more than their proportion of the moisture evaporated from the ocean, and the interior regions are in consequence robbed of their share.

The opposing wall of a high mountain range rising so as to face a wind blowing across a warm ocean surface furnishes the conditions suited to give rise to the largest possible amount of precipitation. This we see well exemplified in the case of the Khassia Hills, which are so situated as to receive upon their flanks the hot and necessarily extremely moist wind blowing across the Bay of Bengal, and which in consequence are the recipients of the largest rain-fall known anywhere in the world.* The same thing is exemplified, only in a lesser degree, in many other localities; as, for instance, along the northwest coast of England and Scotland, and on the western slopes of the Scandinavian Range. Similar conditions may be noticed along the western coasts of New Zealand and of Patagonia, and also on the Pacific coast of North America from California northward. In each of the cases mentioned, with the exception of that of the Khassia Hills, the shores of the land masses rise precipitously from the ocean to a very considerable height, and face the return trade-winds, which are thus forced to deposit the moisture which they have taken up in their passage across the water surface. In the case of any one of these rainy belts we have to go only a short distance inland, sometimes only a few miles, to find the precipitation greatly diminished, or even reduced almost to nothing.†

* At Cherapunji, in Assam, for instance, Professor Loomis gives, on the authority of Blanford's Report on the Meteorology of India, the mean precipitation at 492.45 inches, the elevation of the station being 4,125 feet. Of this quantity no less than ninety-five per cent falls during the six months from April to September inclusive. He adds: "When the wind on the Bay of Bengal blows from the south the rain falls almost incessantly; and when the wind changes to the west or the northwest, the rain ceases almost entirely."

† For abundant illustrations of this statement, see the detailed maps illustrating the precipitation of various

The effect of a mountain range in entirely cutting off the precipitation from another one parallel with and adjacent to it, but on the leeward side, as respects the prevailing wind, has already been alluded to, in the case of the Sierra Nevada and the Inyo Mountains.* Where several ranges run parallel with each other, each one farther to the leeward being somewhat higher than the more windward ones, the result is that the precipitation is distributed among them all, in the form of rain on the lower ranges, and in that of snow on the higher, if these latter extend above the snow-line. This is well exemplified in the case of the Northwestern Himalayan Mountains, which rise from an intensely hot and dry country at their base, in a series of parallel chains, the whole breadth of which is not far from 300 miles. The Outer (or lower) Hills — the Sub-Himalayas, as they are also called in the reports of the Government Geological Survey — receive their precipitation in the form of rain, and in larger quantity as the successive chains rise higher and higher; when we reach a sufficient elevation snow takes the place of rain wholly or in part; and, finally, the culminating range is capped with glaciers surpassing even those of the Alps in magnitude.

As has been seen above, shores — especially those rising in bold mountains — opposed to prevailing winds from the ocean receive an abnormal share of the precipitation. But the continental masses themselves are the cause of winds which blow towards them, even in direct reversal of what would, were it not for the existence of the land, be the normal direction of the wind-currents. The class of winds thus set in motion by the effect of the land masses is known as the monsoon winds. These exist, in fact, almost everywhere along the coasts of the continents, especially in the warmer climates. There is no region, however, where the monsoon winds occur on so grand a scale as on the southern coast of Asia, and especially over Peninsular India. Here, indeed, the system of the trade-winds is entirely reversed during half the year, the effect being that what would otherwise be a barren waste, like by far the greater part of Persia and Arabia, is in most years

regions; for instance, that of Europe, by Krümmel (in the Zeitschrift der Gesellschaft für Erdkunde zu Berlin, Vol. XIII.). The contrast in the amount of rain-fall immediately on the coast, and at a little distance from it, in regions situated as above described, is most remarkable. Hardly anywhere is it possible to find a more striking instance of a sudden change from a moist to a dry climate, than is presented in going up the Columbia River, in Oregon. Within a distance of a few miles one passes from a region exhibiting all the attributes of a richly watered country to one of extreme dryness, the transition being marked by an almost instantaneous change in the whole character of the vegetation. Here, of course, it is the Cascade Range which cuts off the precipitation from the region to the east of it.

* See *ante*, p. 32.

bountifully watered by the rain brought from the Indian Ocean by the southwest monsoons. It is the intense heat of summer acting on the vast elevated mass of Central Asia which brings about this reversal of the trade-winds. Let the temperature diminish, High Asia would be less heated than at present, the force of the monsoons would be diminished, and the supply of moisture to India would fall off in a corresponding ratio.*

It may not be out of place here to introduce a few words in regard to the climatic conditions prevailing over the region to the west of India, and especially on the eastern and southern sides of the Mediterranean, to the drying-up of which considerable space was devoted in the preceding chapter. The question is, How does meteorological science account for the present prevailing deficiency in that region of the moisture so necessary for vigorous life and prosperity, no regard being had to past or future possible changes?

The opinions of meteorologists on this subject have not been entirely concordant.† The essential fact is this: that the region in question is some-

* Nothing was said in the previous pages in regard to the constant and apparently more frequent recurrence of famines in India, occasioned by deficiency of rain, as an exemplification of the desiccation so evidently going on over the vast region adjacent on the north and northwest. A single quotation may, however, be given here, as summing up the painful facts within the compass of a few lines. It is from Walford's Famines of the World: Past and Present [Being Two Papers Read before the Statistical Society of London in 1878 and 1879 respectively, and Reprinted from its Journal]. London, 1879. That author writes as follows: "I have endeavored to make my table of famines complete as to India in modern times. The first great famine there of which we have any knowledge — many earlier ones of lesser magnitude have occurred — was that of 1769–70, 'when the Government did not attempt to cope with the disaster; when the people died of starvation by hundreds of thousands; and a desolation spread over the country, the marks of which have not wholly ceased' (*Vide* Col. George Chesney, 'Indian Famines,' in [the magazine called the] 'Nineteenth Century,' [number for] November, 1877). We see in our table that it is estimated that *three millions* of the population then died of starvation, an estimate I am not inclined to deem exaggerated; and we are told that Bengal has been subjected to famines periodically since — why *since*, as distinguished from *previously*, does not appear. [The reader will notice this last remark of Mr. Walford, as indicating increasing desiccation in very recent historic times.] In 1799 there was again a famine in Hindostan, and in 1803. In 1810 there was a famine in the North-west Provinces, and from 2 to 8 per cent of the population died, 90,000 in one central district alone! In 1813–14 Hindostan again; in 1332 in Madras, when 200,000 perished in the district of Guntoor. In 1837–38 in Northern India, 'the worst famine of this century,' — but this was written before the more recent famines we now have to record. In 1861 famine in North-west Provinces; in 1866, 'awful famine' in Orissa, one million and a half, half the population of London, reported to have perished. In 1874 the Bengal famine, which cost the Government 6½ millions sterling for an organized system of relief; and lastly that of 1877, more terrible perhaps than any during this century, over which our Indian experience extends, and which it is estimated will cost in all nearly 10 millions sterling."

† Wojeikof, in his latest publication on the distribution of the rain-fall throughout the world (in the Zeitschrift für wissenschaftliche Geographie, Vol. I. [1880] p. 193), thus explains the peculiarities of the climate of the region bordering on the Mediterranean and of the Sahara: "The Sahara is for us the true type of a desert. It has been often maintained that the cause of the scarcity of rain was to be sought for in the northeast winds blowing from Central Asia. This is an error. In the first place we find that south winds are rather common, in winter, in Syria, Mesopotamia, Persia, etc., in short in the whole region which separates Central Asia from the

what centrally situated in the midst of a vast area of land, and therefore must partake of the conditions imposed by the necessities of such a position; these, as has already been explained, include deprivation of rain-fall, to an extent proportioned to the size of the continental area, and the manner in which the necessary moisture is cut off on its edges by interposing mountain ranges. The Mediterranean is not large enough to do away with the character of a single mass of land which the three continents—Europe, Asia, and Africa—would really have in perfection, were it not for the interposition of that inland sea. The most that it can do is, to mitigate in some degree, in the immediately adjacent region, what would otherwise be an entirely insupportable dryness.

Besides this, another unfavorable condition for the countries adjacent to the Mediterranean, and especially for those to the east and south of it, results from their position with reference to the great mass of intensely heated land of Equatorial Africa, and the proximity of the trade-wind belt on the south. The effect of this is, that the winds sweeping over the region in question are mainly northerly, and are not moisture-bearing, because they are moving toward warmer, and not toward colder, regions.

The reversal of the trade-wind by the mass of Central Asia, producing—as has been described—copious rains, in ordinary years, in India, is only very slightly effective in Persia or Arabia, and hardly at all in Northern Africa. The Monsoon system of India and the region farther east depends on the proximity of the ocean, which cannot be heated up by the summer

Sahara: we have therefore no reason to expect to find in that desert any constant current of air coming from Central Asia. The northeast winds which, during the winter, blow in the Sahara, have their origin chiefly in Africa itself. In the summer Asia is still less the cause of the dryness of the Sahara, for at that season the barometric pressure in the interior of that continent is less than it is in Africa, and the wind blows toward Asia from eastern Europe: Asia, in fact, forms in summer a gathering-place [Sammelplatz] for the winds. Since in summer the atmospheric pressure over the Sahara is small, especially over the southern part of the Desert, the air draws thither from the Mediterranean Sea, from a portion of the Atlantic Ocean; and since the pressure in general in the eastern part of the Sahara is comparatively low, north winds arise (that is to say, westerly or northwesterly winds, which by the effect of the earth's rotation are converted into northerly winds). The constancy of the summer north winds is proved by the observations of all travellers, not only in the Sahara but in Egypt. Since these winds come from the Mediterranean Sea, which at that season is much colder than the Desert, they of course cannot bring rain. Even along the coasts of Algiers, in Sicily, Malta, etc., it hardly ever rains during the summer on account of the prevalence of north winds; and the same result is still more reasonably to be expected in the Sahara, since there the air is still warmer and drier. Northern Arabia, as well as a part of Mesopotamia and Syria, is also extremely dry. The constancy of the north winds during the summer causes the scarcity of rain at that season; during the winter southerly winds do blow occasionally, and do bring some rain, but on the level areas only in very small quantity, since the air is too dry, and obstacles which would cause the air to rise and become suddenly cooled are not present. In the mountains and in their vicinity the precipitation at this season is more copious."

sun as the land masses can be. With the great expanse of Africa adjacent it is not possible that similar effects should be produced in the countries to the west of India. What little does result in that direction is not enough to remove the general character of dryness and consequent desolation impressed on the whole region by the combination of unfavorable circumstances.

From what has been said in the preceding pages it is thought that the reader will have been fully convinced of the truth of the statement that the form, size, and position of the land masses change the whole character of the distribution of the precipitation from what it would normally be were the earth entirely covered by water; the effect of this being that certain regions are entirely deprived of moisture, while upon others the rain-fall is enormous in amount. It has also been shown on what conditions the total amount of precipitation on the earth depends: that if this amount were considerably increased a proportionate irregularity in its distribution would be maintained, there seems to be no reason to doubt.

The amount and distribution of the fall of rain and snow in the polar regions is a branch of the present inquiry in regard to which our data are far from being satisfactory in kind or amount. The published rain-charts afford but little light on this subject. That, as a general rule, precipitation is much smaller in high northern latitudes than nearer the equator has already been stated. Professor Loomis says: "Beyond the parallel of 60° N. latitude, at a little distance from the ocean, the mean annual rain-fall seldom much exceeds ten inches; and there are apparently regions of great extent in Asia and North America where the annual rain-fall is less than ten inches."* But that the precipitation is very irregularly distributed in the Arctic lands and seas is probable; and that it is very large over a certain area is hardly to be denied. In regard to the Antarctic region we know even less than we do of the opposite pole. This ignorance of the meteorological conditions of the polar areas is all the more to be regretted, since the conditions in those parts of the earth are continually being appealed to by glacial geologists as illustrations of what took place in lower latitudes during the "Glacial epoch." It will be best, therefore, to reserve what we have to say on the subject of the precipitation in the north and south polar regions until the next chapter, when a concise statement will be given of all that is definitely known of the meteorological conditions prevailing in the extreme northern and southern latitudes.

* Contributions to Meteorology. Sixteenth Paper, Am. Jour. Sci. (3) XXIII. p. 22.

What has been said in the present section in regard to precipitation, and the general nature of the causes regulating its amount and distribution, will find its proper application farther on. It seemed impossible to proceed in this discussion without giving the reader a sub-stratum of facts on which to base the arguments which are next to follow. The main points sought to be made, in reference to the amount of precipitation as influenced by and dependent on temperature and area of surface exposed to evaporation, will be admitted by all without hesitation. In reference to the Glacial epoch, difficulties may arise in seeking for the causes of a fall of rain and snow so irregular in its distribution as that demanded by the conditions then prevailing. But it will be better to state these difficulties frankly, even if it be found impossible to meet them satisfactorily, rather than to pass them over entirely, or to assume, in pointing them out, that they need no explanation because quite analogous to what is now taking place on the earth's surface, while in reality all the facts are entirely opposed to any such assumption.

A few words may be added in reference to the conditions favoring precipitation in the form of snow; but not much need be said on that subject at present, since it will necessarily come up again in various forms in the succeeding chapter. The reader must bear in mind, however, that while a low temperature is necessary to the formation of snow, the moisture from which that snow is formed must have come from a comparatively warm region. Thus the grand glaciers on the summits of the Himalayan ranges are made up of frozen water which has been brought—in large part, at least—from the surface of the Indian Ocean. Portions of the earth where the mean temperature is very low remain almost bare of snow throughout the year, while other regions, in close proximity, and where the temperature is higher, are covered with immense glaciers, as will be more fully set forth in the next chapter.

Since decrease of temperature is the result of increased elevation, we are able to have any amount of cold in any latitude. Even at the equator eternal snow may and does exist; and if conditions were favorable, such snow accumulations might occur on the most gigantic scale. In fact, most of that part of the earth in high latitudes which has a very low mean temperature is but thinly covered by snow, and that not remaining through the year; while the cold, because elevated, regions within the tropics, or in their vicinity, are always the abode of snow and ice.

SECTION V. — *Has the Extent of Land Surface on the Globe been on the whole increasing with the Lapse of the Geological Ages?*

It having been shown in the preceding section that precipitation depends — in part, at least — on the relative extent of land and water surface on the globe, the inquiry next suggests itself, whether we have reason to believe that this relation has undergone a change with the lapse of the geological ages; and, if so, in what direction. Have the continents grown larger, or have they diminished in size? Or, on the other hand, has the gain made by the rise or formation of new land in one region been more or less than counterbalanced by sinking in another quarter? If it can be shown to be, if not absolutely certain, at least altogether probable that, on the whole, the tendency of geological events has been toward an increase of land-surface on the globe, as the epochs followed one after the other, then we have here correspondingly strong reason for believing that the amount of precipitation must have diminished in a similar ratio, unless it can be shown that some other cause affecting rain-fall has been, at the same time, working in the opposite direction.

A broad field of inquiry is thus laid open before us, and one which not only connects itself in the most direct way with the topics embraced in the present volume, but which also has intimate and interesting relations to several other geological and zoölogical questions. It will not be possible to handle the subject, at the present time, in anything like an exhaustive manner; but some general results can be indicated which will be of importance in connection with the problem before us.

It would seem that the first step in the inquiry is not a difficult one to take. So far as the continental masses at present existing on the globe are concerned, it is hardly possible to deny that they have, on the whole, with the lapse of geological time, been growing. We can make out, by means of sections and geological maps, what has been the character and mode of formation of the different deposits which have succeeded each other, and in doing this we find among the stratified rocks, as we recede in geological time, an ever increasing predominance of those containing organic forms of such a character as to indicate clearly the presence of the ocean at the time the strata in question were formed. An exception to this statement must be admitted in the case of the apparently abnormal appearance of a large area of land surface during the Carboniferous epoch, not only in North America, but in parts of Europe. This fact, like most of the others connected with the formation of coal, and especially that of this particular epoch, is exceedingly difficult of explanation. It does not, however, seem to the writer to militate against the general result stated above, namely, that the land masses have, *on the whole*, been gaining in area during the successive geological ages.

As an excellent illustration of this, reference may be made to Delesse's maps showing the areas occupied by land in France during the successive geological epochs.* On examining these, it will be seen at once that, on the whole, the gain of land surface in that country, from one epoch to another, has been most decided. This has been especially the case since the beginning of the Cretaceous period. There was a rapid diminution in the area occupied by the ocean, over the region now included within the limits of France, from the Eocene period on. At the beginning of the Pliocene there were still extensive lacustrine areas covered by fresh or brackish water, all of which, however, entirely disappeared before the end of that epoch.

This sequence of geological events is best seen in the case of a country like France, where the series of formations is remarkably complete, and the recent orographic disturbances not so general and so intense as to obscure the relations of the various groups. In regions, like that of Northeastern North America, where there are immense gaps in the geological series, similar conditions as to the increase of land surface with the lapse of time may exist, although not so easily recognized by an inspection of the map. We have, however, in this region a very decided predominance of marine strata in the earlier formations, and great and perhaps, in some regions, sudden gains of land surface at several successive epochs. Indeed no one can for a moment doubt that, taking the areas occupied by the present continents into consideration, land has been, on the whole, gaining upon the sea most decidedly.

This indeed seems to be the natural order of things, if simplicity be admitted to be more natural than complexity. Granting that the surface of the globe, in consequence of unequal shrinking while cooling, assumed an irregular form, so that portions were elevated, more or less considerably, above the level of the ocean, then, supposing no farther change of the

* Maps accompanying the "Lithologie des Mers de France, et des Mers Principales du Globe, par M. Delesse." Paris [1871].

earth's form to have taken place, the constant tendency of those geological agencies which we know must have been immediately set to work would be toward increasing the existing areas of land, by carrying the débris of the higher portions into the adjacent regions of the ocean. This statement is, however, based on the reasonable assumption that the ocean shore would not be extremely precipitous. Where it was so, the increased area of land created out of the detrital material brought from the adjacent higher regions would form but a narrow strip, because so great a depth would have to be filled up before the new land formed would begin to emerge from beneath the surface.

In point of fact, a large portion of the stratified masses from which the continents have been built up does consist of detritus abraded from adjacent higher land areas and carried to the sea and then laid down on its floor. The coarser this material was, the nearer to the shore it became deposited, and the more rapidly the formation increased in thickness. Far from the land the accumulation would go on very slowly, since only the very finest detritus could be carried to such a distance; and although the material secreted from the ocean water by organic agencies would be added to the detrital deposits thus formed, after the death of the animals or plants by which the solid material was thus eliminated, the increase made in this way would also be very slow. Thus the body of strata representing any particular group is likely to be much thinner when its formation has taken place in deep water than it is where deposited in close proximity to the land. This is well illustrated by the relative thickness of the different groups of the Palæozoic series, as exhibited along the line of the Appalachian Range and in the Mississippi Valley.

The continental masses may then be looked upon as being mainly built up of the eruptive and azoic nuclei and abraded material derived from them. The former constituted a part of the original crust of the earth raised above the other adjacent portions; the latter, the result of the action of the erosive agencies upon the elevated portions. But, of course, where disturbances of the crust have been continued in the same region, after stratified material has been laid down adjacent to the central elevated masses, the detrital beds have, in turn, been lifted up, often metamorphosed, and themselves subjected to erosion, the result being an aggregation of stratified material either gathered around a central nucleus of crystalline rock, or more often along the flanks of an axially situated mass of a similar character, the original force having been exerted synchronously, or nearly so, along a line perhaps thousands of miles in length. These elevated portions of the land which have furnished the detrital material have usually continued to do so during the successive geological ages, as is shown by the fact that the grandest mountain chains of the world have, spread out at their bases, or lying in crumpled folds on their flanks, the various members of the geological series, if not in absolutely unbroken sequence, at least in something more or less nearly approaching that condition.

In view of these facts, it is evident that there must have been, on the whole, a gain of the land on the earth's surface, unless it can be shown that, in former ages, there have been one or more reversals of the existing conditions of tendency to elevation and depression over different areas of the earth's surface. In other words, the land must have been gaining in area from the growth of the existing continents, unless other continents have been disappearing at the same time to counterbalance the increase thus produced. The superiority of the theory, from the point of view of simplicity, that the oceanic basins, having once been begun by the earth's shrinkage, would continue to remain areas of depression, will not fail to be recognized. Little as we really know of the precise mode of action of the causes which have, during the successive geological ages, been at work to raise certain portions of the earth's crust and to depress others, it certainly throws additional difficulties in the way of our comprehending the process of land-making and mountain-building, to have to admit that areas of elevation and depression have from time to time been arbitrarily interchanged as to their position. On the contrary, it appears decidedly more philosophical to assume that areas of depression have always continued to be such, and *vice versa*. What originally determined the relative position of these areas, we know not; but, having been marked out, their persistence seems, if not a necessary result, at least more reasonable than the contrary condition of things.

The probability of the view of the persistence of the various regions of elevation and depression has been greatly strengthened, since recent investigations have proved so clearly how great the mean depth of the ocean is, as compared with the mean elevation of the land. Recalling, in the first place, the already mentioned fact of the great preponderance of the surface of the ocean over that of the land (the two being to each other nearly as eleven to four), and considering that the mean depth of the ocean is now known to be at least as much as ten times as great as the mean elevation of the land, and perhaps somewhat more than that,* it becomes evident that the depressions of the earth's crust are its really important features, so far as relief of surface *with reference to sea-level* is concerned, and that the portions of the continental masses above that plane of reference are almost insignificant in volume compared with the dimensions of space occupied by water.

From this fact we are enabled to draw conclusions of some importance with reference to the question now before us. The great depth of the ocean seems to indicate that the depressions in which its water is accumulated have had, from the beginning of the earth's history, a character of permanence. While the continental masses, over a large portion of their areas, at least, are so low that comparatively slight oscillations of level would raise them above and depress them below the sea, we can hardly conceive of the exertion of a force sufficiently intense to raise any considerable portion of the deep sea so as to convert it into dry land. That the low portions of the continents have been raised above and sunk below the water, and that this operation has been more than once repeated in certain regions, is a well-authenticated fact in geology. The areas thus affected have been large as compared with the dimensions of the continents, but small in contrast with the magnitude of the ocean surface; and, as before remarked, the tendency has on the whole been to an increase of the continental masses, although considerable portions of these are at the present slightly depressed below the sea-level.†

Dr. W. B. Carpenter was the first to call attention to the importance of the argument in favor of the stability of existing continents derived from the facts just stated in reference to the great mean depth of the ocean. He thus concisely states the case: "The enormous depth of the Oceanic sea-bed, as compared with the height of the Land above the sea-level, renders it very unlikely that any subsidence of a Land-area should be compensated by such

* The mean height of the land-masses of the globe above the sea-level is usually taken, following Humboldt's authority, at about 1,000 feet. Recent investigations tend to make it somewhat more than this. The mean depth of the ocean has been recently carefully computed by Krümmel, with a result of 11,280 feet. (See Morphologie der Meeresräume, Leipzig, 1878, and Kettler's Zeitschrift für wissenschaftliche Geographie, Vol. I. p. 40.) A ratio of one to ten for the mean elevation of the continental masses as compared with the mean depth of the ocean is probably as fair an approximation as can be made at the present time. Dr. W. B. Carpenter, however, puts this ratio at one to thirteen. He computes the volume of the ocean-water at thirty-six times that of the land above the sea-level.

† As, for instance, the region adjacent to Great Britain on the south and southeast.

an uplifting of the Ocean-floor as would raise it above that level. Thus, supposing that all the Land of the globe were to sink down to the *sea-level*, such subsidence would be balanced (according to the current idea of compensatory alternation) by an elevation up to that level of a portion of the average Ocean-floor, amounting to no more than 1-36th of its existing area. On the other hand, the sinking of such an area as that of Papuo-Australia (which forms about 1-17th of the existing land-surface) to the depth of the average *ocean-floor*, would require to balance it an elevation of the whole remainder (13-14ths) of the existing land to *double* its present average height above the sea-level."*

The first recognition of the grand idea of the persistence in position of the areas of elevation and depression appears to be due to Dana, who, in his memorable address before the American Association for the Advancement of Science, delivered in 1855, thus stated his views: "This simplicity of ocean boundary, of surface features, and of outline, accounts for the simplicity of geological structure in North America; or we may make the wider statement, that all these qualities are some way connected with the position and extent of the oceans, they seeming to point to the principle, that the subsidence of the oceanic basins had determined the continental features; and that both results were involved in the earth's gradual refrigeration, and consequent contraction."

In the first edition of his "Manual of Geology," published in 1863, Dana made a still farther step towards the recognition as a general idea, applicable all over the world, that land and ocean have not, to any marked extent, changed places with each other during the geological ages. The following quotation will show exactly how far he progressed in this direction: "The continents and oceans had their general outline or form defined in earliest time. . . . . The oscillations, plications, and elevations alluded to began in the Azoic age; hence the conclusion that the oceanic basins and continents were early outlined is unavoidable. The sinking of the ocean's bed and the rising of the continents were concurrent effects of one cause. . . . . If then the continents were from the beginning the nearly stable areas (as appears also from the absence of volcanoes from their interior, while they abound in the oceans) the pressure of the subsiding oceanic portion has acted against the resisting mass of the continents; and thus the border between

* See Dr. W. B. Carpenter, on "Land and Sea considered in relation to Geological Time," in Report of Royal Institution of Great Britain, Meeting of Jan. 23, 1880.

them has become elevated, plicated, metamorphosed and embossed with volcanoes."*

It is not, however, by any means possible to admit that the statements made in the last paragraph quoted are in accordance with the facts. The areas now occupied by the continents have not "from the beginning" been the "nearly stable areas." On the contrary it is precisely these areas which have been regions of disturbance, and in some parts of enormous disturbance; and it is not alone their edges which have been "elevated, plicated and embossed with volcanoes." † This, however, is not a subject coming up for discussion at the present time; at least not to any farther extent than is necessary to throw light on the question whether the quantity of land on the globe has been on the whole increasing. Nor can this question be considered to have been by any means decided by what was published at this early stage of the inquiry. Dana does indeed state that the outlines of the North American continent had been marked out at an early period in geological history, or, to quote his exact words: "The continents and oceans had their general outline or form defined in earliest time. This has been proved with regard to North America ‡ from the position and distribution of the first beds of the Lower Silurian, those of the Potsdam epoch. The facts indicate that the continent of North America had its surface near tide-level, part above and part below it, and this will probably be proved to be the condition in Primordial time of the other continents also. And if the outlines of the continents were marked out, it follows that the outlines of the oceans were not less so." §

* Manual of Geology, Philadelphia, 1863, pp. 732, 733.

† In support of the statement here made, reference may be made to the well-known facts in regard to the geology of the Cordilleras of North America. Here, over a belt a thousand miles in width, during the Tertiary period — not to speak of what happened before that — volcanic action took place on a most gigantic scale. By this action mountain ranges were built up; and not only by this, but by actual uplift, the entire Rocky Mountain Range in the interior of the continent having received its form and final finish in Pliocene times. Similarly it may be said of Asia that its elevated portion is central in reference to its development. The land of that continent has grown around a central nucleus; and not been formed by plication and embossing of its edge with volcanoes.

‡ This statement seems to have been based on the investigations of Messrs. Foster and Whitney, as published by them in their Lake Superior Report, and in an article read before the American Association for the Advancement of Science, at the Cincinnati Meeting, in 1851, and entitled, "On the different systems of elevation which have given configuration to North America, with an attempt to identify them with those of Europe." So little was known at that time, however, of the geological structure of the great complex of the Cordilleras, that the statement quoted above could not have been said to be "proved with regard to North America," even if it were considered to be so for the northeastern and eastern portions of the continent.

§ Manual of Geology. First Edition, 1863, p. 732.

It does not follow, however, that because the outlines of the existing continents were marked out at an early period in geological history, other continents might not also have been marked out, and then, after existing for a time, have sunk beneath the ocean and disappeared forever. This indeed is a very difficult and complicated question, which, even with all the assistance rendered by recent investigations of the nature of the sea bottom, the depth of the ocean, and the structure of the land masses, cannot as yet be positively answered. There is no doubt, however, that the subject of the possible or probable former changes in the area and distribution of the continents is one of the greatest interest, not only from a purely geological point of view, but from its connection with various inquiries with which physical geographers are now occupying themselves. The study of the conditions and laws regulating the development and distribution of plants and animals during the successive geological ages is now one of the greatest possible interest, and on this study, as well as on the closely associated one of the phenomena of climatic change during the successive epochs, the question of the stability of the existing continents has a direct bearing.

A careful consideration of the conclusions drawn by Dana, from facts connected with the geological structure of North America, with regard to the stability of the ocean areas, seems to indicate that the land alone could not furnish positive evidence on this point. What can be definitely made out may be thus succinctly stated, as in part recapitulatory and in part explanatory of that which has been briefly set forth in the preceding pages.

The framework of the existing continents was marked out at an early period in the earth's history, and as it appears probable, by the development in the earth's superficial layers, or crust, of certain areas having a tendency to become more and more depressed below, and of others to become more and more elevated above, a certain plane of reference, namely, the surface of the oceanic waters, which connect with each other all around the globe, and form what in point of fact is an arbitrary "bench mark," although none the less a convenient and indeed indispensable one. Simplicity of theory, in the absence of any positive information as to why these regions of depression and elevation have been thus selected and arranged with reference to each other, leads us to the inference that what would appear to us an arbitrary interchange of position between these areas is not likely to have taken place. This inference is still farther strengthened by the facts thoroughly established in the course of the extensive series of deep-sea soundings made by recent hydrographic explorations, namely, that the mean depth of the ocean is much greater than the mean elevation of the land above the sea-level. This, taken in connection with the fact of the much larger area of ocean than of land on the globe, means, of course, that certain regions of the earth have assumed a slightly elevated position with reference to the arbitrary datum-line above mentioned; and that certain other much more extensive regions have, synchronously with that elevation of the higher smaller portion of the earth, become very considerably depressed. This fact adds great strength to the argument in favor of the permanency of the continents derived from the superior simplicity of that view as compared with the opposite one.

As to what has happened over the subsiding areas of the earth's surface during the geological ages we know little with certainty beyond the fact of the subsidence itself, because they have been for the most part deeply covered by water. The areas of elevation, on the other hand, we know to have been subject to disturbances, very different in character and amount, however, in different regions. The larger part of the land of the globe has not been raised to a very great elevation above the sea-level; certain other regions of limited extent, on the other hand, have been; and in a few places an elevation has been attained just about as great as the greatest depth of the deepest known portions of the ocean. These loftiest areas belong to the great mountain ranges of the globe, and are the culminating points of certain regions which appear to have been rising during a long succession of geological ages, since they have accumulated on their flanks stratified masses largely formed from the detritus brought down from the adjacent higher regions, and which from the character of the fossil remains which they contain are known to have occupied a long succession of ages in their formation. Other ranges, of less elevation, are found to belong to regions over which the elevatory force has long ago ceased to act. But the fact that the great mountain chains — the Himalayas, the Andes, the Cordilleras of North America, the Alps — all have included within their masses strata of various ages, down to and including the Tertiary, is proof that, on the whole, the tendency of high regions has been to rise still higher. This is another fact rendering probable the correctness of the view that the continents and the oceans have not interchanged positions. This theory cannot, however, be considered as having been proved with certainty by arguments drawn from the class of facts to which our attention has thus far been turned.

Recent hydrographic investigations carried on so actively by different nations over almost every portion of the globe have furnished information in regard to the nature of the sea bottom which has an important bearing on the question before us, and which, taken in connection with the argument already advanced, justifies us in declaring that the theory of the permanence of the great oceanic areas is one which, if not absolutely proved to be true, is at least very strongly supported by facts.

Guided by his investigations of the sea bottom along and near the course of the Gulf Stream, Agassiz as early as 1869 was enabled to throw a new light on the subject of the persistence of the continental and oceanic areas. In his report on deep-sea dredging in the Gulf Stream, published in 1869,* he says: "From what I have seen of the sea-bottom, I am already led to infer that among the rocks forming the bulk of the stratified crust of our globe, from the oldest to the youngest formation, there are probably none which have been formed in very deep waters. If this be so, we shall have to admit that the areas now respectively occupied by our continents, as circumscribed by the two hundred fathom curve or thereabout, and the oceans, at greater depth, have from the beginning retained their relative outline and position; the continents having at all times been areas of gradual upheaval with comparatively slight oscillations of rise and subsidence, and the oceans at all times areas of gradual depression with equally slight oscillations. The fact that upon the American continent, east of the Rocky Mountains, the geological formations crop out, in their regular succession, from the oldest azoic and primordial deposits to the cretaceous formation, without the slightest indication of a great subsequent subsidence, seems to me the most complete and direct demonstration of my proposition. Of the western part of the continent I am not prepared to speak with the same confidence. Moreover, the position of the cretaceous and tertiary formations, along the low grounds east of the Alleghany range, is another indication of the permanence of the ocean trough, on the margin of which these more recent beds have been formed. I am well aware that in a comparatively recent period portions of Canada and the United States, which now stand six or seven hundred feet above the level of the sea, have been under water; but this has not changed the configuration of the continent, if we admit that the latter is in reality circumscribed by the two hundred fathom curve of depth."†

* Bulletin of the Museum of Comparative Zoölogy. Cambridge, Vol. I.

† l. c., p. 363.

Here we have, for the first time, a distinct recognition of the fact that the continental masses have appended to them a border area which is indeed submerged, but to so slight a depth that the portion thus covered by shallow water really forms a part of the continent itself. Slight oscillations of level may therefore alternately cover and expose these border areas, as well as the similarly situated low portions in the interior of the continent, without changing in any essential degree the real relations of land to water surface on the globe considered as a whole. These changes of level which we know to have taken place have often been of the greatest importance in the geological development of the land, while at the same time not essentially interfering with the present outline and position of the oceans.

Similar views to those cited above as having been enunciated by Dana and Agassiz have quite recently been published by several distinguished European geologists and physical geographers, among whom Professor A. Geikie and Dr. W. B. Carpenter may be especially mentioned.* Professor Geikie thus sums up the results, as formulated in his own mind, of the study of the sea bottom as recorded in the work of the Challenger expedition: "From all this evidence we may legitimately conclude that the present land of the globe, though formed in great measure of marine formations, has never lain under the deep sea; but that its site must always have been near land. Even its thick marine limestones are the deposits of comparatively shallow water. Whether or not any trace of aboriginal land may now be discoverable, the characters of the most unequivocally marine formations bear emphatic testimony to this proximity of a terrestrial surface. The present continental ridges have probably always existed in some form, and as a corollary we may infer that the present deep ocean basins likewise date from the remotest geological antiquity." †

Since therefore it may with truth be stated that there is a strong body of evidence and a marked unanimity of opinion among the most eminent physical geographers and geologists in favor of the idea of "the *permanence*, throughout all geological time, of what may be called the frame-work of the existing Continents, on the one hand, and the *real* Oceanic basins on the other," — to use Dr. Carpenter's own words, — it appears equally proper to

* See "Geographical Evolution," a lecture delivered before the Royal Geographical Society at the Evening Meeting, March 24, 1879 (Proc. R. G. S., New Series, Vol. I. p. 422), and the Address by Dr. Carpenter to which reference has been previously made (*ante*, p. 210).

† l. c., p. 428.

draw the inference that the body of land on the earth's surface has, on the whole, been increasing during the geological ages. The main support of this view is, however, to be found in the fact, demonstrated by geological investigation, that the structure of the great mountain chains shows that their upheaval has been the result of a long-continued process, during which a tendency to rise has been counterbalancing the influence of the erosive agencies always at work carrying down material from the rising areas to form the stratified deposits on their flanks. Hence the highest chains are usually those which contain the fullest series of the geological formations, including the most recent as well as the oldest. It would appear that greater and greater efforts had to be made, as time passed on, to rupture the earth's crust, or at least to raise portions of it above the adjacent regions, and that these efforts were, in the main, most successful either at the very place where effects of the same kind had been previously produced, or else in the immediate vicinity of it. If this had not been the case, new lines of fracture having been started, the old areas of elevation becoming the stationary ones, these latter might have been entirely swept away by erosion. The effect of this would have been, in the long run, to bring the surface of the earth, whether above or beneath the water, to a more nearly uniform level, and at the same time to diminish, rather than increase, the entire area of land surface on the globe. It is true that the ocean would be shallower over certain regions adjacent to the land masses than it now is; but this diminished depth would not have a sensible effect on precipitation, since evaporation goes on from the surface only.

It may now be asked whether, having shown it to be highly probable, if not certain, that there has been during the geological ages an increase of land surface on the globe, we have entirely solved the problem before us. It is admitted that such an increase would necessarily be followed by a diminution of the precipitation, unless counterbalanced by the effect of some other agency working in the opposite direction. Here, then, we have a reasonable cause for the desiccation which has been shown to be taking place over the earth. The continents have become dry, because they have grown large. The total amount of water evaporated has become smaller, because the surface from which evaporation could take place has diminished. The interiors of the land masses are insufficiently supplied with moisture, when not situated in the tropical belt, because their borders intercept the rain-bearing currents coming from over the warm and moist ocean surface and compel them to discharge their contents before they have been carried far inland. This effect would be produced in the case of very extensive areas of land, even where portions adjacent to the sea were not considerably elevated above its level; but where, as is often the case, the borders of the continents rise in lofty mountain chains, there, as has already been shown, the precipitation is likely to be almost entirely cut off from the whole interior region. Again, where the land is so situated that the winds are constantly blowing over it in one direction and from a cooler towards a warmer region, these will be desiccating winds, because their capacity for moisture is increasing as they sweep over the country, and a lack of moisture is the inevitable result.

With these general principles to guide us, we could, if we were able to make out how the growth of any continental mass has taken place, form some idea of the conditions prevailing over the region in question during the successive epochs in respect to the distribution of precipitation. Thus, taking into consideration the known effect of the Gulf of Mexico in mitigating what would otherwise, in all probability, be a serious dryness in the Mississippi Valley, we may infer, not without good reason, that when the water covered an extensive portion of that valley, reaching, as it did in later Tertiary times, up to the mouth of the Ohio and beyond, there must have been a larger precipitation than now takes place over the adjacent region. So, too, when the vast area east of the Ural Mountains was covered by the sea, the ranges lying still farther eastward, in the line of the prevailing winds, must have been favored with a moister climate than they now possess.

Thus we might go on, and endeavor to ascertain what possible changes have taken place in the forms of the land masses during the geological ages, and especially the later ones, and in this manner be put upon the track of the necessarily resulting alterations in the character of the climates of the regions thus subjected to changed conditions in the arrangement of land and water in their vicinity. In doing this, however, we should have to assume that there had been no agency of an opposite character at work, at the same time, tending to bring about results of an opposite character from those indicated as likely to be produced by the enlargement of the continents. This might, indeed, have been the case; but then, on the other hand, there may have been other causes in action not antagonistic to the one dwelt upon in the preceding pages, but in harmony with it, and thus lending their aid to bring about a still more marked result than would have been produced by orographic changes alone.

An agency of this character has already been indicated in the preceding section, namely, an increase of temperature, and it will be proper to take up next this branch of the inquiry, and endeavor to make out whether, in addition to the evidence of a former higher temperature afforded by the phenomena of desiccation, we can produce other and more positive proofs of a change of this character having taken place. It is true that we have in the orographic development of the continental masses an effective cause of a diminution of the rain-fall; but we are not at liberty to take it for granted that this has been the only one, unless we can prove that all the phenomena of desiccation can be accounted for by orographic changes alone.

This, however, does not appear to be the case. The drying-up of the continents described in the earlier sections of this chapter seems clearly to present features which cannot be explained on the simple assumption of an increase of area in the adjacent land masses. This, as the writer believes, cannot but be apparent to the candid inquirer, who will carefully take into consideration the various facts previously presented, especially when it is remembered that the evidence here laid before the reader forms but a small part of that which might have been furnished, had space permitted. The decrease of the water surface in such cases as that of the Aralo-Caspian Basin or Great Salt Lake is of a character which cannot be fully accounted for by orographic causes alone; and the same may be said of several of the other regions where similar phenomena have been shown to be taking place. The gradual diminution of the moisture, as well as the shrinking of the water surfaces in general, seems abundantly proved in regions where it is hardly possible to admit that any orographic changes are going on. To use a homely illustration: there are regions where we can see that the kettle has been more or less completely emptied by having been upset; in a few cases we may perhaps admit that a crack in its side has let the water run out; but there are more instances in which the marks indicate clearly enough that the work has been done without violence, and that the kettle has been deprived of its contents by simple evaporation.

In view of what has here been stated, it appears that, if not compelled to look for other causes than orographic ones to account for the phenomena of desiccation, we are at least justified in doing so; and since it has been shown that a diminution of the solar radiation, or in other words a decrease of temperature on the earth's surface, would certainly be such a valid cause, we are naturally led to inquire whether any proofs, aside from such as have already been furnished, can be obtained of any such decrease having taken place during the geological ages, either during their entire duration, or for any portion of it. Such an inquiry will naturally connect itself with an investigation into the changes of climate which may have taken place on the earth, however caused and wherever prevailing, and will likewise lead to the discussion of the various and somewhat numerous theories of climatic change which have been promulgated by different writers on the subject of "geological climates." Moreover, our attention will be turned, more decidedly than it has thus far been, to the vertical element in the orographic changes which have taken place on the earth's surface, and especially with reference to the causes giving rise to precipitation in the form of snow rather than in that of rain. A portion of this review and discussion will be brought forward in the following section; a part of it will, on the other hand, find its most natural place in connection with that which is to be given in the chapter devoted to the Glacial epoch.

SECTION VI. — *Examination of the Evidences of former Changes of Temperature on the Earth. Has the Solar Radiation been diminishing in Intensity during all or any Portion of the Geological Periods?*

As has been shown in the preceding pages, the proofs of desiccation during the later geological periods, over various portions of the earth's surface, are ample. After the facts bearing on this question had been laid before the reader, it was explained, in the course of a discussion on the causes influencing precipitation, that there were two prominent ones which would tend to a diminution of its quantity; namely, an increase in the amount of land surface on the globe, and a decrease in the intensity of solar radiation. It was farther shown that the first-mentioned of these causes had — as was, at least, extremely probable — been in action during the whole time of the accumulation of the sedimentary formations, the continental masses having been growing larger as geological time passed on.

It now remains to inquire whether it is also true, or highly probable, that there has been a tendency to a decrease of precipitation through the agency of the other specified cause, namely, a diminution in the intensity of the sun's heat.

The term "geological climates" is one under which are commonly classed those real or supposed variations of the earth's climatic condition which, having taken place in past ages, before the historic period, can only be proved to have occurred by means of geological evidence.* As so defined, the subject of geological climates is one which has been prominently up for discussion, especially during the past few years. Hardly a week passes that does not add something to the already voluminous literature of this and allied questions. As already explained, however, the subject of desiccation has in the course of these discussions and investigations been very unsatisfactorily treated, having been left out of consideration altogether, or looked upon as merely a phase of the Glacial epoch. Almost all investigators of geological climates have contented themselves with endeavoring to show how the "great ice-age" might have been brought about, not only ignoring the local character of this phenomenon, but paying little or no attention to other lines of inquiry, the following of which might have led them to recognize the fact that they were looking at the subject from a very unsatisfactory standpoint.

It is true, however, that, in spite of the fact stated above, namely, that theories of climatic change have almost invariably proved to be simply theories of the Glacial epoch, there has been considerable discussion in the course of which the subject of geological climates has been handled without assuming that the only important climatic change which the earth has witnessed has been that in which the great ice-sheet made its appearance. Indeed, there is hardly any possible or conceivable theory or combination of theories which has not been brought forward and upheld by some one, and had there been any satisfactory degree of harmony among those investigators who have endeavored to grapple with the entire subject of climatic change, the present writer would not have thought it necessary to add his voice to the discussion. He would not have done so, had he not hoped that he might perhaps apply some of these theories in a manner not hitherto attempted, and, while endeavoring to give due prominence to all the important facts, succeed in bringing the various phases of climatic change into some kind of satisfactory relation to each other.

It will be assumed that the facts set forth in the preceding pages in regard to the desiccation do render it, if not certain, at least probable that other

* This definition is not intended to exclude the seeking of assistance from other branches of science in the prosecution of an inquiry into the climatic changes of past geological times. Whatever light might, for instance, be thrown upon the subject by astronomy would of course be welcomed, and it is from that source especially that possible information as to the causes of any such indicated changes would be expected.

causes than mere orographic ones have been active in diminishing the amount of precipitation on the earth. It will also be recognized as a fact that a diminution in the sun's heat would have a similar effect, and we shall now endeavor to show that, aside from the evidence afforded by the proved decrease of rain-fall, there are satisfactory reasons for believing that the earth's surface, on the whole, is decidedly cooler than it has formerly been, and that this refrigeration is not a temporary phenomenon, but something which has been going on through all the geological ages. If this be true, it follows, as a matter of course, that the so-called "Glacial epoch" was not an exceptional period of cold, which has passed away, and been followed by a return of a previous warmer condition, as is generally affirmed by geologists to have been the case. If, then, a large body of facts can be brought forward indicating that the mean temperature of the earth is becoming lower, it will have to be explained how it could have happened that, at a former time, there were extensive accumulations of snow or ice over certain regions now either nearly or quite destitute of these evidences of a colder climate, — such as glacial phenomena are usually considered to be, — and the occurrence of which has led to the designation of a certain time in the earth's history as the "Glacial epoch."

To avoid complication, and to render the discussion more clear, the consideration of the Glacial epoch will be reserved for another and special chapter, in which the more prominent and important of the theories of climatic change brought forward by investigators in this line of inquiry will be mentioned, and examined, so far as may appear desirable. The reason for this course will, it is believed, become apparent on reading the chapter in question.

We have it as our task then, in the present section, to show that there is strong, and it may even be said abundant evidence of a diminution of the solar radiation during the geological ages. Moreover, it will appear on examination that there is a considerable body of facts, aside from those connected with desiccation, which justify us in concluding that it is highly probable that this diminution of temperature has been continued into and through the historical period, and has been sufficient in amount during that time to bring about distinctly marked changes of climate, attended by such results as, in certain regions, to be of vital importance to the welfare of the inhabitants. And we may begin the discussion by entering on the last-mentioned inquiry, namely, whether there is any proof of a diminution of temperature on the earth since civilization became so far advanced that historical records of the movements of the human race began to be preserved.

The first source, in this connection, to which the inquirer would naturally look for information would be the records of instrumental observations taken all over the world. In the present stage of meteorological science we should expect to find evidences of climatic change, as recorded by instrumental measurements, in one or both of two conditions, variations in the mean temperature and in the mean amount of precipitation. The variations in the direction and force of the wind form an important element of climate, but observations of this kind have not been taken with accuracy until within a few years, the machinery for that purpose being somewhat complicated and expensive.

It might be supposed that among the proofs of desiccation over the earth's surface the results of instrumental observations indicating such decrease of rain-fall would have been brought forward. This has not been done; but it must not be inferred that a drying-up could not have been going on, because it cannot be proved by recorded observations of the rain-gauge to have done so. Neither should we be justified in assuming that an absence of proof of this kind in reference to precipitation would be sufficient reason for not searching for instrumentally recorded evidence of a change of temperature. The conditions in regard to determinations of mean temperature and of mean precipitation are considerably different, as will be briefly explained.

Variations from year to year in the mean which would result from a long series of observations are for the same region or country often very great, even over areas where the precipitation is quite large; and in regions where it is very small, this irregularity is still more striking. Thus at San Francisco, between the years 1850 and 1872, the annual amount of rain ranged between 7.4 and 49.27 inches. In parts of Lower California, on the other hand, it is stated that rain sometimes does not fall at all for several years, but that there are seasons in which several inches are furnished. Evidently in such cases a series of observations extending over many years would be required before what could be fairly called a true mean would be obtained.

There is also another difficulty connected with the determination of the mean amount of the precipitation over any considerable area, namely, that its distribution is locally so irregular. An examination of the rain-charts of England will illustrate what is here meant, for it will be seen at once that places but a few miles removed from each other show very great discrepancies in the mean rain-fall, and it is hardly possible to suppose that a trustworthy result could be had for this country, which forms so small a portion of the entire land area of the globe, without occupying some hundreds of stations. Thus it seems evident that a great number of observers whose work should have been continued over a very long series of years would be an indispensable requisite to the determination of a small secular variation in the precipitation over any region of considerable extent. Neither would it be safe to base any conclusions as to general climatic change on observations which embraced only a small area of land surface, for we know not how far small local fluctuations might be compensated by others of an opposite character at some not far distant point.

The difficulty of obtaining the mean temperature of any particular locality is much less than that of fixing the mean amount of precipitation. At a certain depth, the amount of which is dependent chiefly on the annual range of the temperature, but which is nowhere very great, we come to a point where the thermometer remains stationary at a figure indicating the mean temperature of the year at the surface at that locality. It is true that thermometric observations are not usually taken below the surface, in the region of invariable temperature, because it is the fluctuations from hour to hour, day to day, and season to season, which it is desirable, for ordinary purposes, to know, while the secular variation is a matter of much less immediate consequence. Such subterranean observations have been made, in one locality at least, as will be mentioned farther on.

Accurate records of either temperature or rain-fall do not, however, in any place extend back for any considerable time; that is to say, in comparison with what would be desirable, in order that a positive result should be reached in reference to the question before us.

It is true that all efforts to translate geological into historical time have failed to give any satisfactory result, so that we have no definite idea of how many years would be a reasonable term to fix on as likely to be sufficient for the accomplishment of a change of climate great enough to become decidedly perceptible to accurate instruments of record. Certainly most geologists would admit that a hundred years was a very short period — from a geological point of view — for this purpose. If there had been a distinct diminution of temperature in one hundred years, then — as it appears to the writer, at least — the change would seem to the geologist to be a rapid one, however slow it might be considered by the general public.

Accurate instrumental observations do not go back for as much as one hundred years. A few facts may be given in support of this assertion; and in the first place, in regard to temperature records.

A really serviceable thermometer — that is, a thermometer which could be called a scientific instrument — did not exist until Fahrenheit invented his, in 1714. By fixing two points of the scale, he for the first time determined the value of a degree, and made comparisons of temperature at different times and places possible. But it was not until long after Fahrenheit's day that regular observations began to be taken. In Paris there has been a continuous series from 1763 on, the records taken previous to that being more or less fragmentary. In Stockholm regular observations were begun in 1758; in London in 1775.

The existence of a very serious source of error in thermometrical observations was not noticed until 1817, when Arago called attention to the change of the zero-point of the thermometer used in the subterranean apartments of the Paris observatory.* A few years later, in 1822, Bellani, a Milanese observer, recognized the fact that all thermometers are liable to a change exactly such as would result if the bulb began to grow smaller soon after it was blown, and continued to do so for a long time. Of course observations made previous to this discovery, and, indeed, all observations made without special examinations, from time to time, of the accuracy of the zero-point are of no value for use in any such inquiry as that now before us.

Arago, in his investigation of the question whether there had been any change in the mean temperature at Paris, as indicated by the thermometers observed at a depth of twenty-eight meters below the surface, thought that he could go back as far as the year 1776 for comparison, one observation taken in that year having been made with an instrument recently verified.† Compared with the result obtained with the thermometer, the temperature half a century later seemed to have undergone no perceptible change, although the scale of the thermometer observed in 1776 was too small to admit of accurate reading. Arago remarks that there might have been a difference as great as one-twentieth of a centigrade degree, and a little farther on seems to assume that there had been such a change, for he goes on to say: "A twentieth of a degree [centigrade] in fifty years that is

* Œuvres de F. Arago. Notices Scientifiques, Tome V. p. 642.

† By Messier. l. c., p. 645.

a tenth in a century. This would be only one whole degree of variation in a thousand years!" *

Arago finally concludes that, by extending the thermometric comparison from 1776 to 1852, there would be instrumental evidence of an increase of temperature to the amount of one-tenth of a degree, and he remarks as follows: "Thus, instead of a diminution of temperature at Paris, we seem to have made out a slight increase [nous serions arrivés à un léger réchauffement]. However, these observations would have to be continued for at least half a century longer before we could say with certainty that this tenth of a degree of which I have just spoken is not an irregular and accidental oscillation."

The result indicated by Arago, as he himself admits, is too small in amount and uncertain in character to be accepted as a basis for any generalizations; and the same may be said of all the other investigations which have been made by meteorologists in working over the records of temperature observations for the purpose of endeavoring to make out whether proofs of a secular change of climate could be obtained. The general result of these investigations seems clearly to be that no positive change of temperature can be made out as having been instrumentally determined. A few of the most important researches of this kind may here be noticed as proof of the statement just advanced.

Professors Loomis and Newton investigated the question "whether the mean temperature of New Haven, Conn., had changed since the time of the earliest recorded observations." † Their material for this work consisted of more or less fragmentary observations, dating back, nominally, to 1778. There is no proof furnished that the instruments employed were sufficiently corrected for the errors known to be inherent in all thermometers, as mentioned above, so that any result obtained can hardly be considered as of much value. The authors conclude as follows: "The final result is that the mean temperature of New Haven by the last 45 years, is one-fifth of a degree [Fahrenheit] lower than by the first 41 years; but this quantity does not exceed the probable zero error of most of the thermometers employed in the observations; and we must conclude that if the mean temperature

* Arago farther adds: "The two epochs thus compared embrace between them a period during which certain parts of France have been stripped of their forests [fortement déboisées]. The mean temperature of Paris has, however, undergone no perceptible change in consequence of this disforesting."

† See Elias Loomis and H. A. Newton, On the Mean Temperature, and on the Fluctuations of Temperature, at New Haven, Conn., in Transactions of the Connecticut Academy of Arts and Sciences, Vol. I. p. 194.

of New Haven has changed at all since 1778, the change amounts only to a small fraction of a degree, and cannot certainly be decided from the observations. It is, however, noticeable that the difference for the summer months is quite large, considering the length of the period from which the result is deduced, and seems to indicate a slight moderation in the heat of our summers." *

It should be noticed here that the tendency of all thermometers is to rise, as already explained; and that if, as it appears, the instruments were not carefully corrected from time to time, the results of the observations are very probably higher than the truth.

Mr. Schott has worked up the temperature observations collected by the Smithsonian Institution, embracing a large amount of very poor material, mostly taken by volunteer observers with little regard to scrupulous scientific accuracy.† His results, in so far as they concern the point under discussion, are summed up by him in the following words: "There is nothing in these curves [of secular change in the mean annual temperature] to countenance the idea of any permanent change in the climate having taken place, or being about to take place; in the last 90 years of thermometric records, the mean temperatures showing no indication whatever of a sustained rise or fall. The same conclusion was reached in the discussion of the secular change in the Rain-Fall, which appears also to have remained permanent in amount as well as in annual distribution." ‡

It must again be called to mind that, in spite of Mr. Schott's declaration, there may have been during the time specified a diminution of the temperature, to a not inconsiderable amount, counterbalanced apparently, however, by the already mentioned tendency of all thermometers to rise, not uncommonly as much as one or two degrees, which rise may and often does continue through several years. In short, a result apparently indicating that the thermometer has remained stationary is in reality more likely to be a proof of a real sinking of the temperature, unless it is shown, at the same time, that this source of error has been most carefully guarded against by

* l. c., p. 237.

† Tables, Distribution and Variations of the Atmospheric Temperature in the United States, and some Adjacent Parts of America. By Charles A. Schott, 1876. Smithsonian Contributions, Vol. XXI.

‡ l. c., p. 311. The reader will notice that during the century when this country was being most ruthlessly stripped of its forests, the examination of the recorded rain-fall appears, according to Mr. Schott, to have "remained permanent in amount, as well as in annual distribution." This item of evidence may be added to what has been already given on this point in a preceding section.

the observers, which is not the case as respects the observations taken under the direction or supervision of the Smithsonian Institution.

E. Plantamour has published, in several elaborate papers, the results of the working up of the meteorological observations made at Geneva, in Switzerland.* These papers, to which we shall have occasion to refer again, are most admirable specimens of critical and scientific ability in the handling of a mass of material, of the probable accuracy of which we are justified in having a high opinion. This opinion is based in part on the fact that Plantamour himself does not feel authorized to accept the observations made previous to the year 1826 as being accurate enough for use in an investigation of the kind proposed. The series therefore is a short one, embracing a period of only fifty years, or from 1826 to 1875, but its value is unquestionably greater than it would have been had the results of the earlier inaccurate observations been embraced in the investigations. So far as the question of a secular change of the temperature is concerned, no definite result appears to have been reached by Plantamour. The addition of the observations of the ten years 1865 – 1875 to the series 1826 – 1865 gave a mean one-tenth of a degree (centigrade) higher than obtained for the latter series by itself; but this difference is too small to be considered as furnishing positive testimony on the point in question.

Similar negative results in reference to proofs of secular change of temperature seem to have been obtained by other meteorologists in Europe, notably by Dove and Quetelet; at least the writer has not been able to find anything in their numerous publications on climate to justify the conclusion that positive proofs of any increase or diminution of the temperature had been afforded by the observations worked up by either of these eminent specialists in this branch of scientific inquiry.

The only investigations which seem to lead to a positive result are those of Glaisher; and as this has been repeatedly quoted and much commented on, a more detailed reference may here properly be made to it, although, for reasons which will be given, the present writer places no confidence in the conclusions drawn by that author. Mr. Glaisher's results may be thus concisely stated. The fifty years which elapsed between 1813 and 1863 being

* Professor Plantamour's papers will be found in the Mémoires de la Société de Physique et d'Histoire Naturelle de Genève, Tomes XIII., XIV., XIX. (p. 201), and Tome XXIV. (p. 397). The latter is by far the most elaborate investigation of all, and embraces the whole series of observations from 1826 to 1875. Consult also "Du Climat de Genève," a separate work by the same author, published at Geneva in 1863.

divided into two groups of twenty-five years each, the mean of the first period was found to be 48°.61; that of the second, 49°.18, a difference of 0°.57 (Fahrenheit). Taking the observations made from 1770 to 1860, a period of ninety years, and dividing this into three equal portions, the mean temperature of the first thirty years was found to be 47°.73; that of the second period of the same length, 48°.47; that of the third, 49°.03 — an increase of 0°.74 as between the first and second periods, and of 0°.54 between the second and third.*

In estimating the value of these results, notice must be taken of the fact that the locality where the observations were made is one in close proximity to a city of five millions of inhabitants, and in the midst of a region most densely populated. And it must be remembered that the change in respect to number and density of population which has taken place since the beginning of the period embraced within the investigations of Mr. Glaisher has been enormous.† It is a well-known fact that cities are considerably warmer than the more thinly inhabited country otherwise under similar climatic conditions. Statistics prove this to be true; and there could be no doubt that such would be the effect of an immense aggregation of population within a limited space, even if there were no statistics bearing on this question. Many millions of tons of coal are burned in and about London during every year; and the whole mass of brick of which the city is built is heated during the entire winter, and more or less in the summer, many degrees above the natural temperature. There can be no question that conditions such as are here indicated vitiate all observations made in or near large cities, with a view to the determination of any possible secular variation of the temperature; and that, in consequence, Mr. Glaisher's results are not to be accepted as throwing any light on the problem before us.

To sum up what has here been brought forward in regard to the determination of the question of a possible decrease of temperature by means of the records of instrumental observations, it has to be admitted that, at the present time, there is little or no hope of reaching in that way any result which can be depended on, or accepted even as probable. The length of time

* This abstract of Mr. Glaisher's results is taken from Cosmos, 2me Série, Tome V. p. 676, the original authority not being at hand at the moment of the present writing.

† The population of London has increased, since the beginning of the present century, from a little less than one million to nearly five millions (included within the Metropolitan and City Police districts). During the year 1880 – 81 no fewer than 24,945 new houses were built, and seventy miles of streets added. The increase in the consumption of coal has been in a much greater ratio than that of the population.

during which accurate observations have been taken is not sufficient; and most of the longer series of records of temperature come from observatories situated either within or very near to cities where the conditions have not remained the same, but have been rapidly changing, and in such a way, we have good reason to believe, as to produce a decided effect on the temperature. The most satisfactory result is that from the cellars of the Observatory at Paris; but even here we are not certain that all sources of error have been avoided. If they have been, we may infer that the change of climate at Paris, so far as temperature is concerned, has not been sufficient in fifty years to sensibly affect the thermometric mean.

If, as appears to be the case, instrumental observations have been carried on for too short a time, and too imperfectly made, to justify us in expecting that their records should furnish positive information in regard to any suspected change in the temperature of the globe, the question arises, whether trustworthy conclusions cannot be drawn from data obtained in some way not connected with the use of instruments, but leading to results of a similar character to those which might be furnished by a large number of instrumental observations made in many localities and with a sufficient degree of precision. For instance, historical records of important events connected with climate, changes in the distribution of cultivated plants, changes in the character of forests, migrations of nations, dying-out of the inhabitants of any particular region, — such occurrences as these might be shown to be of such a nature as to be accounted for only by supposing or admitting that the climate of the country from which the evidence came had undergone a change during the corresponding period. It will readily be seen that there are many occurrences of sufficient importance to the welfare of the people to be handed down in their traditions or historic records, and which might be legitimately used in the manner thus indicated. An investigation of this kind, however, opens too wide a range of discussion to permit of any thorough working up of the subject. The most that can here be done is to give the general results at which the present writer has arrived, after examining with considerable care all accessible authorities.*

By far the most important and elaborate publication relating to the question whether there is evidence, not instrumental, of a change of temperature during the historic period in any part of the globe is that of Arago, to which

* The author hopes to be able, at some future time, to set forth more fully than can here be done the various facts collected by him in reference to evidence of changes of climate in historic times.

reference has already been made.* Parts of this investigation are, from the nature of the case, extremely vague; while in regard to certain regions the evidence seems to be quite full and convincing.

So far as the present writer is able to make out from a careful perusal of Arago's work, it appears that the evidence collected by him does on the whole point to a deterioration of the climate of the world, in the sense of a refrigeration; and that for certain countries the facts furnished in the volume in question, supplemented in some cases by more recent information from other quarters, do justify us, most decidedly, in drawing the inference that their climate has become colder to a quite appreciable amount.

Here a few words may be introduced as to the geographical position of those regions which might be expected to furnish evidence of the kind here called for. Of course only countries sufficiently civilized to be in possession of historical archives of some completeness, and going back to times considerably remote, would be likely to be of help to us in this investigation. For instance, it is very possible that if we had some tolerably complete record of the movements of the various aboriginal tribes or nations on this continent from the earliest period of its inhabitation by man, this information could hardly fail to throw light on the climatic question. But in the absence of any written history, and with only vague traditions and scanty monumental relics to guide us, we are likely to be left for an indefinite period in doubt as to how far those indicated migrations from north to south were the result of an irresistible impulse to escape from the rigors of a climate growing too severe for an easy or comfortable existence into one better adapted for that end. In regard to the countries about the Mediterranean, on the other hand, of which we have more or less complete written descriptions going back for two thousand years at least, and in some cases monuments with inscriptions and pictorial illustrations throwing light on times much more distant from us than that, we have already seen that evidence of climatic change of the most convincing kind, drawn from historic records, has been furnished for that region. Indeed, there is reason to believe that when this subject comes to be more systematically investigated, there will be much more light thrown upon it from that quarter.

Again, if a country had, within the historic period, just reached the point where, owing to the deterioration of its climate, it had become difficult for

* Sur l'État Thermométrique du Globe Terrestre. Œuvres de F. Arago. Paris, 1865. Notices Scientifiques, Tome V. pp. 184–646.

the human race any longer to make headway against the prevailing unfavorable influences, we might be furnished with evidence which, at first sight, would seem to indicate that a very rapid change had taken place, but which would perhaps, in reality, only mean that, after a long period of deterioration, a point had finally been reached where resistance was no longer possible, the extreme limit of adaptation having been passed.

A change of climate by which certain portions of the earth's surface should be rendered too hot for inhabitation by man is something of which we have, up to the present time, no experience, for there is no country in this condition. The hot uninhabited regions, like the Sahara, are deserted not because the temperature is high, but on account of the absence of sufficient moisture. So, too, if there are parts of the earth which were formerly too hot to be inhabited by man, but which have now become sufficiently cooled for that purpose, it would be extremely difficult to have any proof of such change having taken place. The question whether there is any geological evidence that the equatorial regions were once too hot for the development of vegetable life will be taken up farther on.

With these introductory remarks, we may turn to the facts collected by Arago and others bearing on the question before us. It will, however, be well to take up first a statement most frequently quoted, and generally considered the most brilliant of all the results of Arago's investigations in this line of inquiry, namely, his supposed demonstration that the climate of Palestine has not undergone any sensible alteration during the past 3,300 years. ["Tout nous porte donc à reconnaître que 3,300 ans n'ont pas altéré d'une manière appréciable le climat de la Palestine."*]

This statement is based on the following evidence. At the most remote historical period the vine and the palm-tree flourished together in Palestine. The date-palm requires a temperature of 21° (centigrade), or a little more, for its successful cultivation; the vine will not bear a higher one than 22°. Consequently, where the palm and the vine grew and throve, there the mean temperature must have been 21°.5, which is stated by Arago to be that of Palestine at the present time, as inferred from the mean temperature of Cairo, the nearest point for which any trustworthy determination was to be had.

It needs but little consideration to show how very slender is the thread of fact on which this result hangs. In the first place, the climate of

* l. c., p. 218

Palestine *has* changed within the past 3,000 years, as has been abundantly proved in the preceding pages. The land once described as "flowing with milk and honey" is now dry, and for the most part little better than a desert. If the mean temperature has not changed, the supply of moisture has certainly been diminished.

Again, the mountainous character of the region in question has not been taken into consideration by Arago. In a country where there are differences of level of several thousand feet, it is evident that we may have very different temperatures in different but closely adjacent regions. As long as it is not known at what altitudes the plants in question respectively grew and flourished, we have no right to draw any inferences as to the mean temperature of the region. This is more especially true, in this case, when reasoning in reference to a country the instrumental records of whose climate are so imperfect as were confessedly those of Palestine at the time of Arago's writing.

Again, it does not appear to be by any means true that the date-palm is limited to a temperature of about 21°. On the contrary, this tree seems able to bear very considerable vicissitudes of climate. According to Fischer, who has published an elaborate monograph on the date-palm,* it appears that its cultivation is successfully carried on in regions embraced between the isothermals of 16° and 30°, and that there is, in fact, no heat known on the earth too great for it to thrive in.†

It is safe to assert, therefore, that no attention whatever need be paid to the statement of Arago that the temperature of Palestine has undergone no change within the past 3,300 years.

The history of the culture of the date-palm appears to furnish some evidence of a deterioration of the climate along the northern limits of its range, where, and where only, we could expect to find proof of a change, if such had really taken place. Fischer cites several instances of localities where this tree was once cultivated and where it no longer thrives. As an example of this, Seistan ‡ may be mentioned, a province on the borders of Persia and

* Die Dattelpalme, ihre geographische Verbreitung und culturhistorische Bedeutung. Von Theobald Fischer. Ergänzungsheft to Petermann's Mittheilungen, No. 64 (1881).

† "We may therefore assume that the highest known mean temperatures are perfectly suitable for it [the date-palm] if other necessary conditions are fulfilled, and that it thrives admirably in the hottest region of the world, namely that enclosed within the isothermal line of 30°. Its limits lie, then, between the isothermals of 16° and 30° C., and the mean annual temperatures of 15°.6 and 28°.5 C." — L. c., p. 53.

‡ Also spelt Sedjestan and Sedschestan.

Afghanistan, once belonging to the last-named country and now to the former. This region has been densely inhabited and highly cultivated, the date-palm flourishing there; but now it is little better than a desert, a cold wind blowing over the plains during the spring and rendering cultivation of fruit trees impossible. This wind seems, from Dr. Bellew's description, as quoted by Fischer, to be much more injurious to vegetation than it was some hundreds of years ago.* Singularly enough, and, as it appears to the present writer, most unphilosophically, the author of this valuable monograph on the date-palm seems to prefer to ascribe the demonstrated change of climate in the region in question to the neglect of cultivation and general injury inflicted by Tartar invasion, rather than to admit that the increased dryness and coldness is the result of natural causes acting independently of man.

It will be impossible, for want of space, to go into any detailed examination of the various evidences of change of temperature brought forward by Arago in the volume under consideration; only some of the instances in which decided results are supposed by that author to have been attained will be mentioned and commented upon.

After the investigation of the climate of Palestine, to which reference has been made above, Arago takes up various countries, not, however, in geographical order, and devotes more or less space to each one, passing some by with a notice of only a few lines, and dwelling at some length on others. The first one mentioned is China, in reference to which an investigation of Ed. Biot is cited, to the effect that the climate of that country can have undergone no change since the most remote antiquity [depuis la plus haute antiquité].†

Egypt, the environs of the Black Sea, Greece, and the vicinity of Rome are next passed in review, without any special result being attained, this branch of the subject being very unsatisfactorily worked up, as compared with what might have been done with the existing fulness of available material. Under the head of "Change of Climate in Tuscany," some interesting

* Edrisi, who was born in the year 1099, speaks of the existence of the date-palm in Seistan; other Arabian geographers mention the same occurrence.

† Not having been able to discover where the original paper of Biot was published, the present writer refrains from any comment on what would appear to be an important investigation. A brief *résumé* of it is given in the Comptes Rendus (Tome XII. p. 349). From this it seems that the conclusions reached by that author as to the permanence in character of the climate of China apply to a zone along the 35th parallel; and that the results were drawn from a comparison of the ancient records of the times of such occurrences as the migrations of birds, the transformations of the silk-worm, and of various meteorological phenomena not specified, with the epochs of the same phenomena at the present day.

old records are mentioned, from which Arago seems authorized to deduce the result that the summers are not so hot and the winters not so cold in Tuscany as they were when the observations in question were made (1655–1670).* The shortness of the series, and the fact that only maxima and minima can be used for comparison, render the conclusions drawn from them of little or no value.

Arago proceeds in his inquiry by quoting a few lines from the Misopogon of the Emperor Julian, describing his life at Paris about the year 358, and speaking of the mildness of the winters, and of the fact that figs and grapes could be grown there without difficulty. No comments are appended to this statement; but in the next chapter, headed "Changes of Climate in certain Parts of France," the author remarks that the documents he is about to submit to the reader seem to prove that in certain regions of France the summers are not so hot as they were formerly. A detailed statement, drawn from ancient records, follows, indicating quite clearly that the grape no longer matures as early as it did 300 years ago, and that since that time the northern limit of profitable or possible viticulture has moved southward. On the strength of this evidence Arago considers himself justified in making the following statement: "Here is enough, as it appears to me, to convince the most incredulous that with the lapse of time the summers have lost, both in France and England, a notable part of their heat." Nothing had been said up to this point in Arago's work in regard to changes of climate in England, although that country is included in the above-cited remark. Farther on in the volume evidence relating to that country is introduced of a character similar to that previously given in regard to France. It is stated, on the authority of an article in the Proceedings of the Royal Institution, that there is abundant evidence that the vine was once successfully cultivated in England, and that it is gradually becoming more difficult to raise even apples profitably.

Arago, after having proved, as he thinks, that the summers in France and England have become cooler, proceeds to discuss the reasons of this change,

* The observations in question were taken by Father Ranieri, at the Convent degli Angeli in Florence, with an instrument which was one of a lot constructed under the supervision of the Academy del Cimento and distributed by them to volunteer observers at different points. Of course these thermometers had no fixed scale, and the observations made with them could not have been used at all had not a box containing instruments of the same make been accidentally discovered in 1828. These were compared with our present standard thermometers by Libri, and the results of Ranieri's observations published as reduced to our scale. This paper forms the basis of Arago's conclusions, which seem to be more positive than those of Libri himself.

and, although this is not exactly the place in which such a discussion should be opened in the present volume, it will be permitted to state briefly the views of the illustrious physicist on the point in question. That there could have been a general change of climate all over the world he thinks impossible, because it has been proved that there had been no change in Palestine. Of the present writer's opinion of the value of that proof the reader has already been informed, and the reasons given for it. The cause must therefore, as Arago thinks, be a local one. The influence of a change of position in the Arctic ice-fields is then discussed, and the sufficiency of that as a cause of the cooler summers not admitted. He then falls back on cultivation of the soil and disforesting of the country as the real agents of the mischief. The reader will notice that while removal of the forests is usually considered to be the cause of heat and dryness, it is here made responsible for just the opposite effects. The arguments by which Arago supports his view that the change of climate in France and England is due to man's interference with nature, are indeed most noteworthy. It is that all this kind of effect is known to have resulted, on an immense scale, in the United States from clearing away the forests and cultivating the soil* [défrichement]. He thus describes the marvellous changes wrought in our climate by the hand of man. After stating the facts in regard to the cooler summers in France, as already mentioned, he goes on as follows: "These same modifications, there is a country where they are now going on. They are developing themselves there under the eyes of an enlightened population; they proceed with astonishing rapidity; they must, in some sort bring on at a blow [coup sur coup] those meteorological changes which several centuries have hardly sufficed to render perceptible in our old Europe. This country — every one knows which one I mean — is North America. Let us see how these clearings are changing the climate. The results can evidently be applied to the ancient condition of our own countries, and we shall thus be able to dispense with *a priori* considerations, which in such a complicated matter would probably lead us astray. Over the whole extent of North America there is a general agreement in recognizing that clearing up the country has changed its climate; and that this change is becoming more and more evident; that the winters are now less severe and the summers less hot; in other words, that

* The word "défrichement" includes both ideas, that of cutting down the forests and of cultivating the land afterwards. "Il se dit en parlant d'une terre inculte dont on arrache les mauvaises herbes, les arbres, les broussailles, les épines, pour la cultiver ensuite." Dict. Fr. Acad. It answers most nearly to our word "clearing."

the extreme temperatures observed in January and July are becoming more nearly alike from year to year." *

The reader is in a position to appreciate the value of these astonishing statements in regard to our climate, from what has been set forth in the preceding pages, in which the negative results obtained by Schott in working up the records of the instrumental observations taken over the whole country have been set forth. The only shadow of evidence which exists in support of Arago's statements as to the changes of our climate is to be found in the paper of Professors Loomis and Newton, to which reference has been previously made.† According to them, the summers at New Haven are cooler than they were at the beginning of the present century.‡ It is noticeable, however, that these authors are inclined to ascribe this increasing coolness of the summers, which they evidently regard as a local matter, to the growth of a great number of trees in the streets of the city, while Arago explains the same change, which he thinks he has proved to have occurred in Europe, and assumes as having taken place here, to precisely the opposite cause, namely, cutting down the forests.

A very considerable amount of evidence has been collected by various authors, to the same effect as that furnished by Arago in reference to Central France, namely, that conditions favorable to the growth of certain plants, especially the vine and the olive, have changed in the course of centuries, so that they can no longer be successfully cultivated in regions where they once flourished.

It is also admitted by eminent physical geographers, that the character and distribution of the forests in various parts of Europe, and especially in the more northern countries, indicate an increase of cold. This appears to be notably the case in Iceland, on the Shetland Islands, and in Lapland, where the birches are said to be dying out and are not replaced by a new growth.

Similar statements are made by many writers on the forests of Switzerland, to the effect that it appears to be more and more difficult for the trees to maintain themselves at high altitudes, a fact analogous to what has been already stated in regard to the Himalayas and the Sierra Nevada. In the case of the Swiss Alps, however, it seems to be increasing cold, rather than dryness, which is bringing about the indicated result. The attention of the

* l. c., p. 236.

† See *ante*, p. 225.

‡ This evidence had not, however, been published at the time Arago's volume was written.

present writer has been called to this dying out of the forests, in the course of repeated visits to the Alps and especially in one made since the writing of this volume was begun. It seems to him hardly to be doubted that the forests in higher parts of both the Swiss and the Tyrolese Alps are suffering from a change of climate, and not, as is usually supposed, from the attacks made upon them by man. These deleterious effects of climate can be studied only at the extreme limits of forest growth, and at elevations and in positions where the difficulty of access and the character of the timber combine to allow the trees to remain in their natural condition. Similar facts in reference to the movement of the northern line of forest vegetation toward the south, in the valley of the Yenisei River, will be found in the various accounts of the geography and geology of Siberia published by the Russian scientific explorers of that region. In many places along the lower part of the Yenisei large trunks of trees are found imbedded in the peat morasses in such a way as to show that they grew on or near the spot where they now rest. From this and other similar facts, it is considered by Schmidt and Middendorff that there can be no doubt that the limit of tree growth has receded toward the South in later historic times.*

According to Dr. F. v. Czerny,† it has been positively made out in Hungary that the vegetation peculiar to the steppe is gradually working its way toward the West. This, however, might be the result of a diminution of moisture, and does not necessarily imply a lowering of the temperature, except in the case of those who, like the present writer, consider the two phenomena as causally connected.

The fact that the name of the month of November in the Russian, Polish, and Bohemian languages (and perhaps in some other Sclavonic tongues) is the same as the word signifying "fall of the leaf," is looked upon by some writers as indicative of a change of climate in the region where those languages are spoken. The trees in that part of Europe do now unquestionably finish shedding their leaves before November begins,

* See F. Schmidt, Wissenschaftliche Resultate der zur Aufsuchung eines angekündigten Mammuthcadavers von der kaiserlichen Akademie der Wissenschaften an den unteren Jenissei ausgesandten Expedition, in Mem. St. Petersburg Academy, Vol. XVIII. 1872, No. 1, p. 26.

† In "Die Veränderlichkeit des Klimas und ihre Ursachen," Wien, 1881. Dr. Czerny mentions the following as authorities from whom he has derived his information in regard to changes of climate in historic times: Studer, Lehrbuch der physikalischen Geographie und Geologie, Bern, Chur, und Leipzig, 1847, II. Theil, pp. 305–308; El. Reclus, La Terre, 3d edition, II. pp. 493–497; and Müller's Kosmische Physik, 4th edition, pp. 510–513.

and the argument thus derived in favor of an earlier setting in of winter in Central Europe is not without weight.

If the ideas which have been advanced in the preceding pages are based on correct principles, we should expect to find the most striking evidence of deterioration of climate in extreme northern countries where, as already suggested, the limit of man's endurance has been reached and perhaps overpassed. Arago himself declares that Greenland "offers the most striking example which can be cited of a deterioration of northern climates." The evidence which he brings forward in support of this statement is, however, extremely meagre, hardly occupying more than a few lines. It is to the effect that the Icelanders who first visited its coasts were struck with its verdure, and for that reason gave it the name of Greenland. Numerous colonies were established there, which throve, multiplied, and carried on a lively commerce with Norway, until about the beginning of the fifteenth century, at which time communication with that region ceased, and the very existence of ancient Greenland began to be looked upon as a myth. In 1816, however, the whale-fishers, having noticed that two hundred square leagues of ice had disappeared, steered westward and rediscovered the country. The climatic changes of the polar regions are thus described and accounted for by Arago in the paragraph which completes what he has to say about the variations of climate in Greenland: "Scientific expeditions sent since that time toward the North Pole have furnished us with precise information in regard to the breaking up of the ice of the polar seas. Currents of warm water which traverse [sillonnent] the Arctic ocean and struggle with the permanent cold of the north pole explain the secular modifications presented by the climates of the most northerly regions."*

While it is believed that the proofs of a deterioration in the climate of Greenland during historic times are ample, the views of Arago, as cited above, in regard to the nature and causes of this change are of the vaguest possible character, and so far as history is concerned entirely incorrect.†

* l. c., p. 243.

† The colonization of Greenland was begun by the Icelanders about the year 986. Their settlements were in two groups, called the Eastern and the Western, the former being in the environs of Julianehaab, in latitude 60°–61°, the latter near Godthaab, latitude 64°. The region thus colonized became what may with truth be called a centre of commercial activity and of geographical exploration. From it those voyages were made which resulted in the discovery and settlement of a considerable portion of the coast of Nova Scotia, Newfoundland, and New England. The ruined remains of the habitations of the colonists are found along the shores of Greenland, between Julianehaab and Godthaab, in more than a hundred places, that region being now occupied only by a few strag-

The climatic phenomena of the Arctic region will come up for consideration, to a certain extent, in the next chapter, when it will be made apparent that the secular variations of the polar climate have not yet been studied out, if such do really exist, although a very large amount of meteorological work has been done in that region since Arago's work was written. It will also be shown that the heated ocean currents in the polar seas, as originators of secular climatic change, are purely a creation of the imaginative brain of that author. Neither the history of the discovery of Greenland nor that of its subsequent decline and rediscovery has been correctly given by him. It does appear to be true, however, that the main fact of the constantly increasing difficulty of supporting life along the shores of Greenland has manifested itself in the decay of the colonies founded there, the abandonment of parts of the coast formerly dwelt upon by a comparatively thriving population, and an increase in the rate of mortality among the Eskimos, who were the original inhabitants, and which appears likely to bring about the complete extermination of the race at no very distant period.

That which seems, beyond a doubt, to have been going on in Greenland finds a parallel in the condition of things exhibited at the present day in Iceland. The fight there against the elementary forces seems to have reached its climax. Long ago the people of that once so favored island yielded the high place which they had at one time occupied in the ranks of

gling, struggling, and rapidly diminishing Eskimo families. The more southerly settlement on the west coast was called the eastern one (Österbygd); the more northerly was designated as the western (Westerbygd). This may easily be accounted for by the fact that the coast of Greenland here trends somewhat northwesterly, so that Julianehaab is really some six degrees of longitude to the east of Godthaab. The intervening space between the two principal settlements was comparatively thinly inhabited; still, remains of old dwellings are found all the way along the coast. Communication was kept up between Scandinavia and Greenland until about the middle of the fifteenth century, when it gradually slackened and finally ceased altogether, and the route to Greenland "passed into oblivion," to use the language of Rink, from whose work on Danish Greenland the facts here stated are drawn in part. The rediscovery of the country by John Davis took place toward the end of the sixteenth century (in 1585), and at that time the Scandinavian colonists had all disappeared and the only inhabitants of the country were the Eskimos. The name "Eastern," as applied to the settlements near Julianehaab, gave the idea, which for a long time held its ground, that this colony was to the east of Cape Farewell, and several expeditions were despatched for its rediscovery, no less than eight having been sent out from Denmark alone, it being supposed that the descendants of the early colonists would be found still living in that region. The last expeditions fitted out for that purpose were those despatched by an English mercantile firm in 1863 and 1864. They all were unsuccessful, and it has now been definitely settled that the lost colonies were not on the eastern side of Greenland at all, but that they were situated as described above. To Mr. R. H. Major belongs the credit of having finally settled this point, and cleared up the difficulties connected with the account of the voyages of the Zeno brothers to this region. (See "Voyages of Nicolò and Antonio Zeno," in the Publications of the Hakluyt Society, volume for 1873.) The above statement of undoubted facts may be compared and contrasted with the account given by Arago of the rediscovery of Greenland referred to in the text above.

intellectual nations, and now, sunk in poverty and distress, the few remaining numbers have begun, after battling against cold, famine, disease, and volcanic agencies for centuries, to leave their native land, several hundreds having already found a home in the valley of the Red River of the North, and in other parts of North America. Whether the large and constant emigration from Norway to this country has for its cause a deterioration of the climatic conditions, the present writer has not the means of deciding. It appears that some Scandinavian authorities are of that opinion, for the Swedish newspapers have been obliged to admit the unwelcome idea of a gradual refrigeration of the country, and the consequently increased difficulty of sustaining life in those northern regions.*

The present writer, after considerable examination of much, if not most, of what has been written in various languages in regard to geographical discovery and commercial ventures in the North Polar regions, has found himself strongly impelled to believe that access to the lands lying in that part of the world has become less easy than it was some centuries ago. If this is not the case, it is difficult to understand how it was that the old navigators, and especially the Dutch, were able to penetrate so far to the north as they did, with such apparent ease. In considering what they were able to accomplish in those days, it is necessary to take into account the fact that their vessels were far inferior in every respect to those now used in northern voyages. Indeed, such a "little cockboat" as that in which Hudson made his discoveries † would not be considered safe for crossing the Atlantic at the present day; much less would it be supposed possible to bore through the ice-pack with one. But unless we are willing to deny statements made repeatedly, and apparently in good faith, by various Dutch and English whaling captains, we are obliged to admit that with these diminutive ill-shapen craft they did frequently reach a latitude of from 81° to 82°, and sometimes a considerably higher one. These statements have, it is true, been scouted as lies by most modern writers; but, in view of all that has been said of a probable deterioration of the climate of those regions, it seems not unreasonable to believe that there may be more truth in them than has been generally admitted.‡

* See "Nature," Vol. XVI. p. 467.

† See Captain Markham's description of this "wretched little craft" in "The Threshold of the Unknown Region," London, 1876, p. 28.

‡ See "Tracts on the Possibility of reaching the North Pole" in "Miscellanies," by the Honorable Daines Barrington, London, 1781, pp. 1–124. The reason why the evidence, so zealously collected and here brought together by Barrington, is so generally discredited, seems to be the fact that the idea of a secular change in the

After due consideration of the facts here presented it seems not unreasonable to make the assertion that, on the whole, there is evidence, very considerable in amount and importance, to the effect that a decrease of temperature during historic times has manifested itself in various ways besides desiccation; and that if such decrease has not yet become perceptible in instrumental records, it is because the conditions under which observations have been taken are not satisfactory, and the length of time they have been kept up is not sufficient for the demonstration of a change, which, although perhaps properly called rapid when looked at from the geological point of view, is very slow as compared with the ordinary progress of historical events. If the facts which have been given in the preceding pages were not supported by others of a similar kind, or if they were contradicted by more definitely ascertained occurrences of an opposite character, it might be justifiable to look upon them with suspicion, and as possibly to be explained in some other way than by admitting an actual cooling of more or less of the earth's surface. When, however, we consider that we have been led directly to the hypothesis of decreased temperature by a long array of facts which seemed to demand the intervention of that agency, our reluctance to accept the indicated deterioration of climate cannot but be lessened. Much more ought this to be the case, if in going back into prehistoric times we find that geology furnishes us with evidence of a similar character; and when we do inquire of that science whether proof can be furnished from its records that the temperature of the earth's surface has been diminishing during the geological ages, we find the answer so fully and entirely in the affirmative that all hesitation about the validity of the conclusions already reached may be laid aside.

It is not intended in the present work to go into anything like an exhaustive investigation of the data on which the assertion made in the preceding paragraph is based. Such a course would involve an almost complete review of the whole stock of geological observations, and the use of an unlimited amount of space for displaying them. All that will be attempted will be to cite a few of the best-known facts by which we are guided toward the conclusion that throughout the earth, from epoch to epoch, a decrease of heat has, on the whole, been the rule.

climate of any region is one as yet quite unfamiliar to the popular mind. So, too, the difficulties in the way of believing the accounts of the voyages of the Norsemen to our own shores will be decidedly lessened by adopting the theory that there has been some deterioration of the climate in this country during the past eight or nine centuries.

A few words must be said, before proceeding farther, as to the way in which the nature of the evidence touching the question before us is affected by the demonstrated fact that the land surface of the earth has been increasing during the geological periods.

It needs but little study of the subject to make it apparent that geological proof of climatic changes must be furnished chiefly by the land. The well-known physical conditions of water are the cause that the ocean, taken as a whole, is cold; only the surface is heated by the sun in warm climates; the great body of the water, even within the tropics, has a temperature at most only a few degrees above the freezing point. Hence, we have but to descend to a moderate depth, even in the warmest climate, to find a fauna indicative of low temperature. It may be said that analogous conditions prevail on the land, where we have only to rise sufficiently in altitude to find the vegetation entirely changed, so that even between the tropics we have an Alpine flora along the higher parts of the mountain ranges. But it must be remembered that the high portions of the land occupy an exceedingly small area as compared with the whole surface of the earth, while almost the whole ocean is very deep. Moreover, the lower portions of the land and of the slightly submerged land masses are the regions where takes place the accumulation of detritus containing the imbedded fossil remains by means of which we are enabled to arrive at a conclusion as to the temperature of the period when the strata in question were formed; for the detrital material itself, if destitute of traces of organic life, would be of no assistance to us in determining that point.

In the case of organic remains enclosed in any assemblage of strata, if they belong to the vegetable kingdom or to land animals, we know that they lived on the surface, and that they are therefore indicative of the temperature of that surface at the time of their growth; but in the case of marine forms we always have the doubt in regard to the depth at which the deposit took place entering in to complicate the inquiry. Moreover, since the earth's surface is everywhere exposed to our examination, we can ascertain the mean temperature of every portion by direct observation, and at the same time find out with ease what forms of vegetable and animal life flourish under the climatic conditions there prevailing.

From the considerations stated above, it is evident that the farther back we go in geological time the greater the difficulties with which we are likely to meet in deciding on the nature and extent of the climatic changes which have taken place. The land area corresponding to each more distant epoch is not only smaller, but it has been exposed to a longer series of geological changes by which the true character of its fossil remains is likely to have been more or less obscured. Thus it is not surprising that it is the more recent formations which, as a rule, furnish the larger portion of the evidence that the climates of various regions have become less warm than they were in former geological periods. And it is not surprising that the most striking evidence of this kind comes from the polar regions; for while we have no experience of a climate too hot for the development of vegetable life, we do have extensive regions where the cold is too excessive to permit the growth of any but the lowest plant forms. Hence the evidence that in the latitudes where now only these low forms occur, there formerly existed an abundant growth of higher ones, such as could only thrive in a much more elevated temperature, is not only decisive as to a change of climate, but most striking as a fact indicative of greatly altered conditions on the earth's surface; while, on the other hand, if regions once too hot for anything to grow have now become cooled down sufficiently to allow vegetation to flourish, it would be almost impossible to procure the proof of such a change, the earlier condition being only indicated by negative evidence, and going back to a period when marine formations were, as a rule, greatly predominating.

With these preliminary remarks, we may proceed to a brief statement of some of the leading facts on which is based the assertion that there is ample proof in the records of geological science that, as a whole, the mean temperature of the earth's surface has been diminishing.

Beginning with the region in which the investigations were made which led to the publication of the present work, we may first call attention to the evidence of a warmer temperature prevailing in the Sierra Nevada during the later Tertiary period. The plants of that region, collected by the Geological Survey of California, have been described by Mr. Lesquereux.* He indicates the results of the investigation, from the climatic point of view, in the following words: "The plants described here from the Pliocene clearly expose the climate of the period which they represent. They record a temperature a few degrees higher, on the average, than that of Middle California, or, like the species of the Chalk Bluffs of the Mississippi, they represent a latitude of a few degrees farther south. . . . . The action of a warmer climate

* See Report on the Fossil Plants of the Auriferous Gravel Deposits of the Sierra Nevada of California, Mem. Museum Comp. Zoölogy, Vol. VI. No. 2.

seems indicated by the oaks of the Mexican type, and by species of *Ficus*; but this is counterbalanced by species of *Betula, Fagus, Ulmus*, etc., whose range of distribution goes much farther north, and scarcely descends below the 30th parallel. Hence, a climate like that of the Gulf shores, the zone of the Live Oak, is about the same as that represented by the fossil plants described from Nevada County." *

In considering, farther, the evidence of changes of temperature through the Cordilleras of North America, to the east of the Sierra Nevada, we have still chiefly to depend on the researches of the same eminent fossil botanist, from the report of whose examination of the Californian Pliocene flora an extract has just been given. On the whole, the facts indicate decidedly a gradual diminution of temperature as well as of moisture during the whole Tertiary period, although there are anomalies, for which, in the present stage of our knowledge of the nature of the causes influencing the distribution and range of both animal and vegetable life, we have no satisfactory explanation to offer, but which we may reasonably encounter without surprise. In an elaborate review of the fossil flora of North America, Mr. Lesquereux thus expresses himself in regard to the point in question: "In considering the distribution of the plants in the whole Tertiary of the Rocky Mountains, there is evidence of a slow upheaval of the land, and a comparative diminution of atmospheric humidity, and consequently of a lowering of the temperature." †

Considering the distribution and relations of the Tertiary fossil plants found in different localities in the Rocky Mountains, Mr. Lesquereux divides them into four groups. The lowest is the so-called Lower Lignitic, characterized by the presence of coal beds of considerable economical importance, and by some designated as of Upper Cretaceous age, by others as Eocene. In this formation palms predominate, whose remains, especially those of the genus *Sabal*, exist in profusion. As indicated by some of their trunks and leaves, these palms were often of great size. Associated with them were genera related to Southern rather than to Northern types, such as *Ficus, Cinnamomum, Magnolia, Myrica*, etc. In regard to the climate of this epoch Mr. Lesquereux remarks, that the atmosphere was evidently charged with a high degree of humidity, the conditions recalling those of the Carboniferous

* l. c., pp. 53, 54.

† A Review of the Fossil Flora of North America. By Leo Lesquereux, Bull. of the Geol. and Geog. Surv. of the Territories. Second Series, No. V. p. 13.

epoch, when wide surfaces of land were slowly emerging from the sea. The character of the climate, as to temperature, is indicated by the remark that the vegetation was somewhat similar in its aspect to that of the swamps now existing along the Gulf shores of the South.

The flora of the second of the four groups mentioned above is largely identical with that of the Lower Lignitic. It differs from it, however, in that it contains, so far as yet known, no leaves of *Sabal* or other palms, although some fruits have been found, which have been referred to that family. This group has not as yet been sufficiently studied to positively fix its position or character.

The flora of the third group is a peculiar one, and decidedly mixed in its character. It is especially known from the fossil plants found in abundance in the shales which overlie the beds of lignite at Carbon. The general character of these plants is decidedly Miocene, and they are closely related to those of the same division of the Tertiary in Europe, and also to those of the Miocene Arctic flora of Greenland and Spitzbergen, of which notice will be taken farther on. Mr. Lesquereux thus characterizes this very peculiar and interesting flora: "Of the fifty-six species which represent it, eighteen are identical with forms of the European Miocene, and thirteen with those of the Arctic flora described from Alaska, Greenland and Spitzbergen. It has still, however, a few species that may be considered remnants of the Lower Lignitic, and are not present in the Arctic Miocene: among others, a *Cinnamomum*, a *Ficus*, a *Smilax*, and a *Rhamnus;* the two last represented by large leaves. It unites therefore in its characters, Miocene Arctic types with Miocene types of Middle Europe, and a few of those of the Lower American Lignitic, considered as subtropical. This reunion of types at the same point indicates the wide extent of the thermal zones during the Miocene period, as well as the concordance of the floras over wide areas, even under distant degrees of latitude."*

The fourth group is much less important, so far as yet known, than the third. The flora is related to that of the European Miocene in but a slight degree, while it is more closely allied to that existing in North America at the present time. "From the preponderance of Conifers and shrubs, the climate of this epoch appears to have been somewhat colder than at the former period."

As Mr. Lesquereux remarks, a wide field is opened for discovery and

* l. c., pp. 12, 13.

investigation in connection with the plant remains contained in the most recent formations, including especially the strata usually referred to the "Drift" by geologists, and in which we might expect to find materials which would throw light on the distribution of the different floras of former geological epochs in the region of the Cordilleras. At present it seems to be impossible to draw any general conclusion, other than that already indicated, namely, that there is proof of a decided lowering of the temperature as we approach more recent times. The genetic connection of one flora with another is involved in the utmost obscurity. The intervention of the so-called "Glacial epoch" has evidently nothing to do with it. There can be no doubt that the flora of the Sierra Nevada, for instance, so different from that of the Pliocene epoch, had assumed its present character before the ice took possession of the higher portions of that range.

The profusion of animal life, during the various epochs of the Cretaceous and Tertiary, in the Cordilleras, has already been alluded to in the preceding pages.* Without attempting to go into details with regard to any precise indications of climatic change offered by the development and disappearance of the successive faunas which occupied that region in later geological times, it will be sufficient to remark that there can be no doubt that, on the whole, the evidence is corroborative of that already presented as furnished by the fossil plants in that portion of the continent. The astonishing profusion of animal life, the large size of many of the species, the predominance of several important genera now limited to the warmer regions of the globe, — as, for instance, the *Crocodilia*, so abundant in the Cretaceous and Eocene beds of the West, — all these facts point in the direction of a decidedly warmer climate as prevailing in those earlier days.

This is emphatically the case in the Sierra Nevada, where the Tertiary strata, as described in the Auriferous Gravels, contain the remains of several genera of land and aquatic animals now limited to regions of considerably higher mean temperature than that of any part of the region at the present time. Among these the rhinoceros and hippopotamus may especially be mentioned, as also various species of the family of the camel. Nor is the fact that so large a part of Central North America was ranged over by the mastodon and elephant in such great numbers during later Tertiary times to be left out of account in considering the probability of the existence of a higher temperature in the days when those animals abounded. Admitting that the

* l. c., pp. 116, 117.

Proboscidæ possessed a remarkable capacity for enduring changes of temperature, it is nevertheless certain that their remains are found in abundance in regions where, at the present time, the vegetation is by no means sufficiently luxurious, or of a character suitable for the support of such large animals.

The following are the conclusions drawn by Mr. S. H. Scudder from an examination of the fauna of the Tertiary lake-basin at Florissant, in Colorado, famous for its prolific beds of plants and insects, and situated in a narrow valley high up in the mountains at the southern extremity of the Front Range of the Rocky Mountains, at no great distance from Pike's Peak, in latitude 39°: "Florissant itself is situated 2,500 meters above the sea, and the presence of so considerable a number of white ants embedded in its shales is indicative of a much warmer climate at the time of their entombment than the locality now enjoys. Investigation of other forms increases the weight of this evidence at every step, for nearly all the species (very few, certainly, as yet) which have been carefully studied are found to be tropical or subtropical in nature."*

Abundance of evidence of a kind similar to that given above for our own western regions is at hand from various other portions of the world. Nothing can, however, be brought forward of so striking a character, in reference to changes of climate since the Tertiary period, as that which has resulted from the various expeditions to the north polar regions during the past few years. The facts are so well known, and have been so fully laid before the public in a variety of accessible forms, that it is not necessary to do more than briefly state the general scope of the deductions drawn by eminent authorities who have worked up the material brought from high northern latitudes, and especially by Heer, in whose hands most of the fossil plants have been placed for examination and description.

Before alluding to the climate of Tertiary times, within the Arctic Circle, as manifested by the richness of the vegetation prevailing over that region during that period, brief notice may be taken of the proofs of a much warmer climate there at an epoch much more remote than that. The existence at various localities, in the very highest northern latitudes yet visited by man, of the fauna and flora of the Carboniferous epoch, shows most conclusively that a warm and equable climate prevailed over the earth at that distant period, and that this condition of things was not something peculiar to the Tertiary epoch. The geologists of the last English expedition, under Captain

* Bulletin of the U. S. Geol. and Geog. Survey of the Territories, Vol. VI. p. 299.

Nares, thus express themselves on this point: "The identity of genera and of some species of the flora of the pre-carboniferous limestone 'Ursa stage' with those of the rocks of Europe, lying immediately above the limestone, point to the equable and identical climate prevailing over very large areas of the earth's surface, and to the local and temporary character of the deep sea conditions expressed by the formation of the mountain limestone, in the midst of a long continental episode, marked by the first rich land flora, in the earth's history, which can be traced both in the old world and the new, from 47° to 74° and 76° north lat., and which was as fully developed beyond the Arctic Circle, as in Central Europe: the leaves of the evergreen tree *Lepidodendra*, and the large fronds of *Cardiopteris frondosa* being as well grown in the Arctic as those from the Vosges and the south of Iceland." *

Rocks of the age of the Carboniferous limestone occur on the north coast of Grinnell Land (near the parallel of 83°), forming cliffs more than 2,000 feet in height. These rocks contain the remains of corals, cephalopods, and encrinites, in regard to which the geologists of the Nares expedition remark as follows: "Unless the corals, which all belong to the Palæozoic types of the Rugosa and Tabulata corals, had marvellous powers of adaptation to different climates, they prove a more equable climate in the world than exists at the present time, and when taken with the fact that the plants of the 'Ursa stage' of the Arctic regions lived before the deposition of the mountain limestone in that area, and doubtless in other areas, and reappeared in the coal measures overlying those limestones in Europe and North America, the supposition that an equable warm moist climate overspread a large surface of the globe during the whole of the carboniferous era becomes something stronger than even a working hypothesis." †

Heer, in his "Flora Fossilis Arctica," also shows that the Carboniferous formation was once extensively developed in high northern latitudes. He describes fossil plants of that age from Bear Island and from Spitzbergen, and indicates the same rocks as occurring on the Parry Islands and in Siberia. He remarks that there was during the Carboniferous epoch a great extent of land near the North Pole covered with the vegetation of that period.

The explorations of Nordenskiöld on the western coast of Greenland have furnished a large number of fossil plants belonging to the Cretaceous epoch,

* A Narrative of a Voyage to the Polar Sea during 1875-6, in H. M. ships "Alert" and "Discovery," by Capt. Sir G. S. Nares, R. N., K. C. B., F. R. S. London, 1878. Vol. II. p. 331.

† l. c., p. 332.

from the examination of which Heer has drawn the conclusion that, during a part of this epoch at least, the climate of the region was decidedly tropical in character. The plants discovered and described by Heer indicate that the Cretaceous formation may properly be separated into two divisions, an Upper and a Lower. The vegetation of the Lower Cretaceous is largely made up of ferns, coniferous trees and cycads; the Upper division is distinguished by the presence of dicotyledonous forms. There is evidence that during the lapse of Cretaceous time the climate underwent a change; but the assemblage of plants in the Upper division, although less tropical in character than the flora of the Lower and earlier portion of the series, is still decidedly one indicating the prevalence of a warm climate during its growth.

The results obtained by Heer in his examination of the Miocene flora from Atanekerdluk and from other localities in West Greenland, and from various points on the eastern coast of that country, as also from Spitzbergen and other places in high northern latitudes, may be justly considered as furnishing evidence of the most positive and remarkable character, in regard to the question before us.* Indeed, hardly any geological investigation has ever excited a more general interest than this of the fossil plants of the Arctic regions, since it proves, beyond the possibility of doubt, that the climatic changes on the earth's surface during the later geological epochs have been of the most remarkable character. That a tropical vegetation existed at the North Pole during Cretaceous times was of itself sufficiently astonishing; but when it had to be admitted that, even down to the epoch of the Middle Tertiary, the Arctic regions were covered with the dense forest vegetation of a warm climate, the contrast between the conditions prevailing at that, geologically speaking, not very remote period and those now existing was too striking not to attract universal attention.

* Heer's results are published in full in the "Flora Fossilis Arctica," and numerous abstracts of them have been given in the scientific journals, as well as in the volumes of travel issued by various explorers of the Arctic regions. A list of these publications will be found in the convenient and carefully edited volume, issued under the auspices of the Government by the Arctic Committee of the Royal Society, for the use of the expedition of 1875 (Manual of the Natural History, Geology, and Physics of Greenland and the neighboring Regions, London, 1875). In the same volume will be found a reprint of Heer's communication to the British Association, at its meeting of 1866, On the Miocene Flora of North Greenland, and also extracts from the third volume of the "Flora Fossilis Arctica" on the Miocene Flora of the Arctic regions, and a translation of a memoir by the same author on the Cretaceous flora and fauna of Greenland, published in the Memoirs of the Swedish Academy of Sciences, in 1874. From these sources the statements in the text have been compiled. The climatic results of Heer's investigations of the Tertiary flora of Switzerland will be found in the work bearing that name, and also as a separate reprint, under the title of "Untersuchung über das Klima und die Vegetationsverhältnisse des Tertiärlandes," Winthherthur, 1860.

The great interest attaching to Heer's results has caused them to be so extensively quoted and commented on, that it is only necessary, at the present time, to recall the essential fact, which is this: that the climate of North Greenland, in the Miocene epoch, was much warmer than it now is, and that this difference of temperature must amount to at least thirty degrees (Fahrenheit). This conclusion is based on a careful review of the climatic conditions indicated by the vegetable growth of the Miocene period in Greenland, as compared with what the same or closely related species prove to be a congenial temperature for their development at the present day. As an illustration of the method by which the results given above were attained, the following quotation may be made from the article on the Miocene Flora of North Greenland, in the British Association report for 1866:* "He [Heer] then selects *Sequoia Langsdorffii*, the most abundant of the trees at Atanekerdluk, and proceeds to investigate the conclusions as to climate deducible from the fact of its existence in Greenland. *Sequoia sempervirens*, Lamb. (Red-wood) is its present representative, and resembles it so closely that we may consider *S. sempervirens* to be the direct descendant of *S. Langsdorffii*. This tree is cultivated in most of the botanical gardens of Europe, and its extreme northern limit may be placed at lat. 53° N. For its existence it requires a summer temperature of 60° F. Its fruit requires a temperature of 65° for ripening. The winter temperature must not fall below 31°, and that of the whole year must be at least 50°. Accordingly we may consider the isothermal of 50° as its northern limit. This we may then take as the northern temperature of the *Sequoia Langsdorffii*, and 50° F. as the absolute minimum of temperature under which the vegetation of Atanekerdluk could have existed there. The present [mean] annual temperature of the locality is about 20° F. Dove gives the normal temperature of the latitude (70° N.) at 16° F. Thus Greenland has too high a temperature; but if we come farther to the eastward, we meet with a temperature of 33° F. at Altenfiord. Even this extreme variation from the normal conditions of climate is 17° F. lower than that which we are obliged to assume as having prevailed during the Miocene epoch. The author [Heer] states that the results obtained confirm his conclusions as to the climate of Central Europe at the same epoch." †

* Reprinted in the "Arctic Manual," p. 368. (A résumé of Heer's discoveries, made by R. H. Scott.)

† Compare Heer, Recherches sur le Climat et la Végétation du Pays Tertiaire, p. 193, and (in German) Untersuchungen über das Klima, und die Vegetationsverhältnisse des Tertiärlandes, p. 127.

G. de Saporta has given a comprehensive review of the indications furnished by fossil plants in regard to the climates of the past geological ages. The present writer thinks it proper to furnish here a brief abstract of the results reached by this eminent authority in fossil botany, which results will be found to be entirely corroborative of those advanced in the preceding pages, and to harmonize, in almost every particular, with the views of Heer and Lesquereux.*

Saporta first considers the plants of the Carboniferous epoch Referring to the investigation of Messrs. Grand' Eury and B. Renault on the vegetation of that period, he says: "Both agree in recognizing the abnormal habit [allures désordonnées] the continuous budding [pousses] prolonged until the stem has become exhausted, and the absence, in fact, of all indications of regular, periodic growth, among the plants which characterize the Carboniferous flora. Thus, it seems that not only was the heat of that period extreme; but, according to all appearances, it was not limited by any periodically returning intervals, comparable with those which characterize our seasons." †

From this point of departure Saporta goes on to show that a seasonal regimen of climate gradually and slowly became established. At a period later than the Carboniferous — the Cretaceous, as already mentioned — the trunks of coniferous trees, with regular concentric rings of growth, bear witness to the existence of seasons, although as yet by no means well marked, as is proved by the presence at the same time of abundant cycads and arborescent ferns, which during that epoch were spread over a large part of Europe and extended to regions beyond the polar circle. Thus, as it appears evident to Saporta, it was not until after the beginning of the Cretaceous that the first traces of a differentiation between the climates of the Arctic region and of Central Europe began to show themselves.

Passing over the remarks made by the author from whose work we are quoting, about the fossil plants of the formations intermediate between the Carboniferous and the Tertiary in Central Europe, we arrive at his conclusions in regard to the later geological periods. He thus states his views: "For the sake of brevity, we will start from the Eocene. Palms are at that

* The *résumé* by Saporta from which these extracts have been taken is to be found in the Revue des Deux Mondes, in the numbers for September 15 and October 15, 1881, (Troisième Periode, Tome XLVII. pp. 335 – 369 and 835 – 866,) under the head of "Les Temps Quaternaires."

† l. c., p. 358.

time widely distributed; with these are present many other kinds of trees indicating a warm climate, and this is not a condition of things peculiar to the valley of the Rhone and to Provence; the same is true of the vicinity of Angers, of Paris, and of London. The Oligocene, with a few shades of difference, shows a continuation of the same conditions; even during the Miocene epoch palms still exist in as high a northern latitude as the parallel of 40°; *Cinnamomum* and *Camphora* reach even as far as Dantzic. As to the Arctic regions, we know, beyond the possibility of doubt, that they have not yet [during the Miocene] become buried under the snow. Immense and heavy forests cover them, wherever land exists, up to the vicinity of the pole itself. However — and this is a point of importance — we are now far from the entire climatic uniformity of the periods anterior to the Tertiary [égalité climatérique absolue des époques antérieures au tertiaire]. The palms stop considerably short of the polar circle; and, in fact, appear never to have reached it at any period. Within that circle, through the whole extent of the Arctic lands, trees with persistent leaves are still present; the larger part of the *Laurineæ*, however, are absent. The forests at all points are chiefly made up of the maple, plane, ash, birch, elm, linden, and oaks with deciduous leaves. There is, however, a decided difference between the climate of the Arctic regions and that of Europe at the same period; a lowering of the winter temperature has taken place, although it has not yet become very perceptible. The polar zone, during the period in question, has about the same temperature as the present temperate zone. Frosts occur there, no doubt; the preponderance of plants with deciduous leaves obliges us to admit that; but the temperature of the cold season hardly reaches as low a point as it does in Paris, at the present day. Perhaps the mountains have already, over their highest portions, become covered with perpetual snow; perhaps already some glaciers have begun to exist, and to make their way from the summits of the ranges into the lower valleys. But the aspect of the country is quite different from what it has since become; life exists everywhere, and it is by no means to be passed over in silence that we find upon the soil, now frozen, the larger portion of the forest trees, which are destined later to make their way toward the south and occupy the northern hemisphere." *

Following still farther the ideas developed by Saporta, we learn that the increased cold and the accumulation of snow and ice in the polar regions put a sudden stop to the forest vegetation which grew and throve there during

* l. c., pp. 360, 361.

the Miocene epoch; for, so far as known at the present time, there was nothing of the kind existing in Pliocene times. Moreover, the gradual refrigeration of Europe from the Miocene epoch on becomes very marked, although in certain localities the Pliocene flora has still the characters indicative of a considerably warmer climate than that which now prevails in the same region. Thus the rich Pliocene flora of Meximieux, not far from Lyons, proves the climatic conditions at that point to have been analogous to those now prevailing in the Canary Islands. Similar facts are reported from the volcanic region of Central France, in the Cantal, where recent explorations have revealed the presence of a flora, imbedded beneath the basaltic rocks, and belonging to the same horizon as that of Meximieux.

It seems hardly necessary to bring forward farther evidence of the prevalence of a warmer climate in former geological ages; this seems to have been clearly enough demonstrated by what has already been stated in the preceding pages. Indeed, that such a refrigeration has taken place is admitted by geologists, almost without exception. That the proofs of this should come, in by far the larger part, from the northern hemisphere, and also from Europe and North America, is not at all surprising. It is there that much the larger portion of the accurate work has been done by which the history of the past has been revealed to the inquirer in this department of investigation. As yet, we hardly know more than the merest outlines of the geological structure of either Asia, Africa, or South America. The forms of the land masses must also be taken into consideration in this connection. The extension of the ocean over by far the larger portion of the southern hemisphere, the almost entire inaccessibility of the Antarctic continent, and the comparatively small amount of exploration which has been done along its borders, — these are sufficient reasons why no proofs of the former prevalence of a warmer climate at the South pole could be expected to be given. Certainly nothing of that kind is possible at the present time, nor does there seem to be much encouragement that such evidence will be furnished in the immediate future.

It will, very probably, be thought by some that the writer has passed over in silence facts which indicate, if they do not prove, that there have been recurrences of periods of cold during the geological epochs; and perhaps it will seem to some that he has omitted to bring forward evidence of a similar kind favoring the popular idea of amelioration of the climate — of certain regions, at least — during the historic period. The theory of the alternation of colder and warmer periods during the geological ages seems, however, to be supported only by evidence of the most vague and unsatisfactory kind: such as it is, it will be noticed, and comments made upon it, in the next chapter, where, as it mostly concerns the so-called Glacial and Inter-glacial epochs, it will find its appropriate place.

When we seek to ascertain whether the prevalent idea of the improvement of the climate in certain countries, as manifested by the lessening severity of the winters and diminution of the intense heat of the summers, has a positive basis of fact, we find it extremely difficult to arrive at a positive decision in the matter. It is not unreasonable to suppose that a decreased emission of heat from the sun would make itself felt, not so much, at first, in any material decrease of the average annual temperature, as in a decreased evaporation from the ocean surface, bringing about the phenomena of desiccation which have been described. The diminished rain-fall thus produced would, very probably, be accompanied by a decreased tendency to atmospheric disturbances and barometric fluctuations. Thus we might have, as a result, that tendency to an equalizing of the seasons of which Arago speaks so positively as having taken place in this country and, to a certain extent, in Europe, and which might be more perceptible to mankind in general than would be the slight diminution in the mean temperature, by which the described change was brought about.

A considerable portion of Arago's investigation, to which reference has in the preceding pages been so frequently made, is occupied by chronologically arranged tables of such natural phenomena as might be expected, from a comparison of the frequency of their recurrence or in other ways, to throw light on the question here suggested. These tables, which were compiled and drawn up by Arago with the assistance of Barral, comprise statements of the years in which the great rivers of Central Europe have been frozen over, as also historical accounts of the occurrence of winters of unusual severity, or of exceptional mildness. Similar facts are presented with reference to the summers, the whole going back, with many breaks and imperfections, to the time of the earliest historical records.

From these tables it is extremely difficult to draw any positive conclusions; indeed Arago is unwilling to commit himself to such. He evidently inclines, however, to the opinion that the deterioration of the climate of France during the historic period, which — as he says — is generally believed to have occurred, does not find a support in the facts cited. He remarks that it is very common, and perhaps natural, to generalize from insufficient data, or to draw hasty inferences from isolated facts, and he gives several instances illustrative of the way in which rash conclusions are or might have been formed, and afterwards set at naught by later events.*

The table of the years in which the great rivers of Central Europe were frozen gives no assistance in coming to a positive conclusion as to any serious change of the temperature in that region during the past 2,000 years. If anything, the indications are that there has been an increased prevalence of severer winters during the later centuries. Thus, for instance, the Seine is recorded as having been frozen over at Paris, *twice* in the 9th century; *not at all* in the 10th, 11th, or 12th; *once* in the 13th; *twice* in the 14th; *five times* in the 15th; *once* in the 16th; *five times* in the 17th; *fourteen times* in the 18th; and *eleven times* in the first half of the 19th. Similar facts are given in regard to the Rhone. But it may justly be said that this apparent increase in the number of times of freezing in later centuries may very possibly be due to the fact that the records of such events kept in modern times are likely to be much more complete, or, at all events, more accessible to research, than those of earlier ages.†

It may be thought that the facts stated in the preceding pages with reference to desiccation, especially in the region bordering on the Mediterranean, indicate so rapid a change of climate, that the records of instrumental observations should — if the change were due in considerable part to diminution of temperature — furnish some positive proof of such diminution. A due consideration of all the facts will, however, lead us to the conclusion, that over regions where the rain-fall has already become diminished to such an extent as to be only just sufficient for the prosperous development of the population, a small farther decrease will be attended by very serious conse-

* For instance, in Provence the thermometer between the years 1768 and 1788 never went lower than —9° (Cent.). This period of twenty years not having shown any such low temperatures as had been previously experienced in that part of the country (of from —15° to —18°), the idea became current that the winters were becoming milder; but in 1789 the thermometer sank to —17°, thus indicating pretty clearly a return to former conditions.

† A good illustration of the positive manner in which statements about changes of climate are frequently made, without any evidence being produced in their support, may be found in a recent charming work entitled "Magyarland" (London, 1881), the author of which declares that the climate of Europe was "much colder" at the time of the building of Trajan's bridge across the Danube [A. D. 103] than it now is. This assertion is accompanied by a statement, that that river was formerly frozen over habitually, so as to be used for the transport of troops, while such an occurrence rarely, if ever, takes place at the present time. The tables in Arago's volume do not sustain this assertion.

quences. In the region in question, orographic causes seem to have been combined with climatic ones in just the way most likely to result in bringing about the rapid desiccation of an extensive region enclosed within the largest land mass of the globe. A very small elevation of the flat regions of Northern Europe and Asia was sufficient to raise an extensive area above the sea-level, and thus to give rise to conditions powerfully affecting the climate of a correspondingly large portion of the adjacent countries.

The causes of the fluctuations of climate, or of the variations in the mean temperature from year to year, are quite obscure. We know, as a fact, that after a few years during which the temperature has been higher than the mean of a long series of years, there will be a succession of colder ones, and that occasionally there will be one or more years remarkable for their abnormal character. The same is true in regard to rain-fall. What causes these successions of periods of warmer and cooler, or of moister and drier, years is as yet a mystery. All attempts to discover the law of their recurrence or to find any regularity about them have failed. It has been a favorite theory with many that these fluctuations might be in some way connected with the sun-spot cycle; but no one has been able to prove that this is the case. It is now pretty certain that the influence of the sun-spots on climate must be exceedingly small,— by far too small to admit of its being taken into account as a matter of practical importance.*

The fluctuations of the weather from year to year are precisely in the same category as the inception of those disturbances of the atmospheric conditions called storms. Of the manner in which storms move after they have been once started, and of the character of the phenomena by which

* Plantamour, in his elaborate discussion of the climate of Geneva, to which reference has already been made, shows that there was a warm cycle between 1826 and 1834, during which time there were seven abnormally warm years and only two cold ones. This was followed by a cold cycle; between 1835 and 1860 there were twenty-two cold and only four warm years; again a warm cycle occurred, and between 1861 and 1875 there were thirteen warm years and only two cold ones. The inference drawn from these facts is thus stated by Plantamour: "There is therefore a very marked predominance of warm years during one epoch, and of cold ones in another; from which it may be concluded that accidental conditions tending to modify the temperature one way or the other, exercise an influence in the same direction, not however in any continuous manner, but with a distinct preponderance during several consecutive years." In regard to the question of a periodical recurrence of abnormally warm and cold years, the following remarks are made by the same author: "It is certainly not possible to discover the least trace of periodicity in the return of these maxima and minima, the mean of which coincides almost exactly with the general mean." The mean temperature of five of the warmest years was found to be 10°.52 (Cent.); that of five of the coldest ones 8°.25; mean of these numbers 9°.38; mean of all the observations from 1826 to 1875, 9°.347. A similar absence of any proofs of regular periodical recurrence of years of greater or less rain-fall is also given by Plantamour as the result of the most careful working over of the observations of fifty years.

they are likely to be attended, much is known; but when these interruptions in the normal atmospheric conditions will take place cannot be predicted, nor is it at all clearly understood why certain regions are peculiarly favorable to their inception. Not the slightest progress has been made towards such an insight into the phenomena of storms and weather fluctuations as would justify the putting forth as a scientific statement of any prophecy of such occurrences, other than as indicated by the mean of the place and season, for even so much as a week in advance.

We assume, then, that it is positively known that the climate of the earth has become colder, in the course of the geological ages; and, moreover, that there is evidence that this refrigeration has been continued in historic time so as to have become sensible and a matter of importance in certain regions where the conditions are such that the limit of endurance, on the part of the inhabitants, had just been reached or even overpassed during the past few centuries. We do not find that we can furnish positive proof, based on instrumental observations, of a perceptible change of climate in the countries where such records have been kept, and for reasons which have been fully explained in the preceding pages. As Arago remarks, a few centuries of accurate observations will probably throw light on the question.

SECTION VII. — *Theories of the Cause of Temperature Changes.*

At the beginning of the present chapter there was suggested, as one of the topics intended to be brought forward in it, an inquiry into the probable cause of the climatic changes shown to have been taking place on the earth's surface during the geological ages, and to be continuing in historic times.

The geologist is not bound, however, to assign a cause for the phenomena which he has proved to have taken place, for the true cause may very probably be one the investigation of which lies outside of his field of work. If the problem discussed be, as is the case in the present work, a climatological one, its solution will most naturally and reasonably be expected to be obtained by the help of mathematics, or of astronomical or physical science. In such a case, the geologist has simply to indicate the results at which he has arrived, stating the facts by which his conclusions are supported, and then to call on those whose proper business it is to throw light on the theory of the causes by which the stated effects have been produced. Still, it seems proper, in the present connection, to state briefly the principal theories of climatic change which have been advanced by various investigators in this line of inquiry, and to make a few remarks on their probability, and their comparative value as fitting the facts which have been developed in the preceding pages. If we find, on examination of that which has been published on the subject, that strong evidence has been presented by the most eminent physicists and astronomers in favor of the existence of a cause which must necessarily bring about the precise results which we have found, as the result of careful geological inquiry, to have been, and to be still, taking place, we shall be authorized to feel that we are supported in our interpretation of the facts. For that the facts are very differently interpreted by different writers on this subject cannot fail to have become evident to the reader.

Even a cursory examination of the theories which have been put forward to account for climatic changes on the earth will show that the important ones may, with propriety, be classed in three rather distinct groups. To the first belong those theories which are of so vague a character that they may be said with truth to adapt themselves to any possible kind of change, or series of changes, of climate. If the conditions which they assume as having taken place could really be proved to have done so, there would be no difficulty about the facts, because they would fit any conceivable scheme of occurrences. The second group of theories or, rather, the second theory, for, in reality, there is only one of this character, looks to a persistent change of climate in one direction, a secular variation of the same kind, always in action and not liable to any interruptions, whether of a periodical or of an irregular character. The third group includes those theories which are based on considerations connected with astronomical phenomena of regular recurrence, and which are therefore supposed to bring about recurrent or cyclical changes in the climates of the two hemispheres, according as they are differently situated with respect to the sun. The various forms of this class of theories, as developed by Adhémar, Schmick, and Croll, have been almost exclusively applied to explain the occurrence of the so-called "Glacial epoch," and they have hardly any significance in their application to the phenomena of climatic change regarded as extending through all the geological ages. These theories will, therefore, not be discussed in this place; but their consideration will be reserved for the next chapter, where attention will be called to them in connection with the facts which they are supposed to explain. It will there be shown, as the writer believes, that the theories in question have no substantial basis of support either in geological facts or astronomical principles. In the same chapter more will be said than has been done in the preceding part of the volume, on the climatological effect of the varying distribution of land and water on the earth's surface at different geological epochs, this last-mentioned cause of climatic change having been prominently put forward by some writers in connection with the phenomena of the Glacial epoch. The extreme improbability of any such changes having taken place on a sufficiently large scale to produce effects of more than local importance has already been fully set forth in a preceding section; how far such variations as might have occurred would have been likely to aid in bringing about the described phenomena of glaciation will be considered in the course of the next chapter.

We may now proceed to a brief review of the various theories which seem properly to come up for discussion in the present connection, beginning with those of the first group mentioned above.

The first theory which may be examined is that of Poisson, to the effect that the earth, together with the solar system to which it belongs, wanders through regions of space having different temperatures. This is an idea which may properly be designated as purely fanciful. The advantage which it offers is, that it may be made to fit any possible combination of facts, so long as local variations of climate are not required to be accounted for. If we wish to explain how it is that, as has been set forth in the preceding pages, the earth's surface has been constantly losing in temperature, we have only to imagine that the solar system has been gradually and steadily moving away from a warmer region in space toward a cooler one.

This idea, however captivating it might be supposed to be on account of its simplicity, has hardly found any favor at the hands of either astronomers or geologists. The former maintain, almost unanimously, that it is inconsistent with the principles of their science, and that there is every reason to believe that, as long as the present solar system holds together, the earth will be dependent on the sun for its climate.

The next theory to be considered is one which has been advocated under various forms and with various modifications. It is to the effect that the position of the earth's axis has been shifted from time to time during the geological ages, either by the shock of a comet, or by the alteration of the position of the centre of gravity caused by the elevation of mountain chains, or in some other way not specially defined. With this theory may be included another one, of similar character, namely, that the earth's crust has slid upon its nucleus, thus bringing different portions of the surface into new relations of climate.

These theories, however, meet with little acceptance on the part of geologists, and still less on that of astronomers and physicists of eminence. The entire weight of mathematical and physical investigation is opposed to the idea that the position of the earth's axis can have changed in any perceptible degree. On this point it is only necessary to quote the statement made by an investigator whose authority cannot be questioned. Sir William Thomson, in a paper on geological climate, published in 1877, thus gives his opinion in regard to the theory in question: "As to changes of the earth's axis, I need not repeat the statement of dynamical principles which I gave with experimental illustrations to the Society three years ago; but may remind you of the chief result which is that, for steady rotation, the axis around which the earth revolves must be a 'principal axis of inertia,' that is to say such an axis that the centrifugal forces called into play by the rotation balance one another. The vast transpositions of matter at the earth's surface, or else distortions of the whole solid mass, which must have taken place to alter the axis sufficiently to produce sensible change of the climate in any region must be considered and shown to be possible or probable before any hypothesis accounting for changes of climate by alterations of the axis can be admitted. This question has been exhaustively dealt with by Mr. George Darwin in a paper communicated to the Royal Society of London, and the requisitions of dynamical mathematics for an alteration of even as much as two or three degrees in the earth's axis in what may practically be called geological time shown to be on purely geological grounds exceedingly improbable."*

Not only is the theory of change of climate by alterations in the position of the earth's axis entirely unsupported by astronomical and mathematical researches, but it is in no respect in harmony with the facts developed by geological inquiry. No one has ever been able to fix on any particular point, or series of points, to which the polar axis could have been shifted, either at once or by a series of changes, which would bring about such climatic conditions as have been proved by abundant evidence to have existed during the successive geological ages. This theory may therefore be laid aside as being in no respect a satisfactory one.

In connection with the second class of theories of geological climates, or

* Transactions of the Geological Society of Glasgow, Vol. V. p. 249.

those which look to a progressive change in one direction, one idea may be mentioned, which for some time had great weight with geologists. It is to the effect that the earth being itself a cooling body, this diminution of temperature of the whole mass of the globe has also been manifested in its effect on climate. The idea might seem, at first thought, a plausible one, for since the theory — if such it may be called — of a cooling earth is one almost universally accepted by geologists, it seems natural that it should be considered as connected with an analogous condition of the surface.

The question whether climate has during the geological ages been affected by the earth's cooling is one, no doubt, of considerable difficulty and complication; but it appears to be one capable of being solved by the aid of mathematics. More than one eminent man has attacked it, beginning with Fourier, and the result is most decidedly against the possibility of accounting for climatic changes on the surface by reference to the condition of the interior of the globe.

Sir William Thomson has expressed himself most emphatically on this point. He says: "Underground heat, though certainly greater in the earlier geological times, cannot, as I have shown elsewhere,* have ever sensibly influenced the climate. Ten, twenty, thirty times the present rate of augmentation of temperature downwards could not raise the surface temperature of the earth and air in contact with it by more than a small fraction of a degree Fahrenheit. The earth might be a globe of white-hot iron covered with a crust of rock 2,000 feet, or there might be an ice-cold temperature within 30 feet of the surface, yet the climate could not on that account be sensibly different from what it is, or the soil be sensibly more or less genial than it is for the roots of trees or smaller plants. Yet underground heat is the hypothesis which has been most complacently dealt with by geologists to account for the warmer climates of ancient times."†

It is evident that the idea of connecting the phenomena of the internal heat of the globe with terrestrial climates, whether of the present, or of past geological ages, must be entirely abandoned, as it has been by most writers on this subject. The hypothesis cannot be allowed to stand as one even of the possible theories of climatic change.

There is a cause to which can be ascribed the gradual refrigeration of the

* See Sir W. Thomson's great paper "On the Secular Cooling of the Earth," in the Transactions of the Royal Society of Edinburgh, Vol. XXIII. p. 157.

† Transactions of the Geological Society of Glasgow, Vol. V. p. 250.

earth's surface, as proved by a long series of facts developed by geological investigation, and of which a brief sketch has been given in the preceding pages. This cause is one which has not hitherto found much favor at the hands of geologists, but which, nevertheless, has the support of the very highest authorities in astronomical and mathematical science. Its nature need here be only briefly stated, the present writer not feeling it necessary to do more in support of its claims to acceptance than to give the opinion of one or two of the most eminent living astronomers and physicists in regard to it, with the additional statement that it is as completely in harmony with the conditions required by geological investigation as it is with the demand of exact science.

What it is, in nature, which has been continuously acting to reduce the temperature of the earth's surface will be made sufficiently apparent by the following quotations taken from recent publications of men occupying the very highest position in the departments of astronomical and physical science. The first of these extracts is from Newcomb, who thus states the case: "But all modern science seems to point to the finite duration of our system in its present form, and to carry us back to the time when neither sun nor planet existed, save as a mass of glowing gas. How far back that was, it cannot tell us with certainty; it can only say that the period is counted by millions of years, but probably not by hundreds of millions. It also points forward to the time when the sun and stars shall fade away, and nature be enshrouded in darkness and death, unless some power now unseen shall uphold or restore her. . . . . We all know that the sun has been radiating heat into space during the whole course of his existence. . . . . The stars radiate heat as well as the sun. . . . . Thus we have a continuous radiation from all the visible bodies of the universe, which must have been going on from the beginning. Until quite recently, it was not known that this radiation involved the expenditure of a something necessarily limited in supply, and, consequently, it was not known but that it might continue forever without any loss of power on the part of the sun and stars. But it is now known that heat cannot be produced except by the expenditure of force, actual or potential, in some of its forms, and it is also known that the available supply of force is necessarily limited. . . . . Hence, this radiation cannot go on forever unless the force expended in producing the heat be returned to the sun in some form. That it is not now so returned we may regard as morally certain."*

* Popular Astronomy, by Simon Newcomb. New York, 1878, pp. 501–502.

Again, we may cite the opinion of another scientist, whose right to speak with authority on a question of the kind now before us will be denied by none. Sir William Thomson has stated his views in regard to the possibility of admitting that the sun may go on radiating heat without diminution, for an indefinite period, in the following language: "Life on this earth would not be possible without the sun, that is, life under the present conditions — life such as we know and can reason about. When Playfair spoke of the planetary bodies as being perpetual in their motion, did it not occur to him to ask, What about the sun's heat? Is the sun a miraculous body ordered to give out heat and shine forever? Perhaps the sun was so created. He would be a rash man who would say it was not — all things are possible to Creative Power. But we know, also, that Creative Power has created in our minds a wish to investigate and a capacity for investigating; and there is nothing too rash, there is nothing audacious in questioning human assumptions regarding Creative Power. Have we reason to believe Creative Power did order the sun to go on, and shine, and give out heat forever? Are we to suppose that the sun is a perpetual miracle? I use the word *miracle* in the sense of a perpetual violation of those laws of action between matter and matter which we are allowed to investigate here at the surface of the earth, in our laboratories and mechanical workshops. The geologists who have adopted Playfair's maxim have reasoned as if the sun were so created. I believe it was altogether thoughtlessness that led them ever to put themselves in that position; because these same geologists are very strenuous in insisting that we must consider the laws observable in the present state of things as perennial laws. . . . . But I believe it has been altogether an oversight by which they have been led to neglect so greatly the fact of the sun's light and heat." *

In another paper on the same subject, Sir W. Thomson expresses himself still more forcibly. He says: "Consider next the evidence with which geological investigation teems of warmer climate all over the earth from equator to pole in the more ancient geological periods. . . . . The one hypothesis [to account for the warmer climate of ancient times] of all hitherto suggested that has received no favor from any professed geologist is that of a warmer sun — the one hypothesis that is rendered almost infinitely probable by independent physical evidence and mathematical calculation." †

* Transactions of the Geological Society of Glasgow, Vol. III. pp. 16 – 17.

† l. c., Vol. V. p. 250.

It may here be permitted briefly to pass in review the various points which have been taken up and discussed in the preceding pages. After a somewhat detailed account of the phenomena of glaciation on the western side of the North American continent, the facts indicating a diminution of the precipitation and a general decrease of water surface in that region during the later geological ages were stated. The same was then attempted to be done for other regions, notably for Asia and the countries bordering on the Mediterranean. The evidence of desiccation, begun certainly before the Tertiary epoch and continued into historic times, seems to the writer to be so cogent that assent to its validity cannot be refused.

That the proved desiccation was not, as is popularly supposed, the work of man, and due to the destruction of the forests, the author next endeavored to demonstrate. It was farther attempted to be shown that the various facts presented indicating decreased precipitation could not be accounted for by simply considering them as a phase of a preceding epoch of glaciation.

This led naturally to an examination of the conditions tending to favor or diminish precipitation, in the course of which it was shown that an increase of land surface on the globe and a diminution of the temperature would be causes acting powerfully to bring about the described phenomena of desiccation. Farther inquiry as to whether geological investigations rendered the existence of the first cause probable seemed to give an affirmative result. The next step was to endeavor to ascertain whether there was proof of a diminution of temperature on the earth's surface. The records of instrumental observations were examined, and the result found to be uncertain, owing to the very short time during which accurate observations had been taken. Other facts, however, seemed to show, almost beyond possibility of doubt, that there had been a marked decrease of the temperature in certain regions during the historic period. The evidence of such diminution during the geological period was found to be abundant and convincing. The cause of such diminution was referred to the fact that the sun is a cooling body, in accordance with the views of scientists of the highest eminence.

It now remains to show that the ideas maintained in the preceding pages are not in conflict with the phenomena of the so-called "Glacial epoch;" and to this our efforts will be directed in the succeeding chapter.

CHAPTER IV.

THE SO-CALLED "GLACIAL EPOCH" AND ITS CLIMATIC CONDITIONS.

SECTION I. — *Introductory.*

HAVING been led, by a careful consideration of facts observed in many different countries, to the conclusion that a diminution of the earth's mean temperature has been taking place during the successive geological ages, we are now obliged to inquire whether it can be true that at the beginning of a certain epoch — the so-called Glacial — a marked climatic change occurred, a period of much greater cold being suddenly entered upon, which, after lasting for a certain length of time, was succeeded by one of increased warmth, a return to previous conditions taking place after a long interval during which a considerably lower temperature had prevailed throughout the earth. That such was the case has undoubtedly, of late years, become the prevalent opinion among geologists, although it is not to be denied that there are some who do not take this view of the climatic conditions requisite for bringing about the phenomena of the Glacial epoch. If it be the correct view, and if it can be shown that for the explanation of these phenomena recourse must be had to a general lowering of the earth's temperature, followed by a change in the opposite direction when the epoch in question came to an end, then it would appear certain that conditions were indicated not at all in harmony with the results supposed to have been reached in the preceding chapter, and we should be obliged to admit that there was some hidden flaw in our chain of reasoning, and that we were mistaken in adopting the view that a gradual refrigeration has been and still is taking place, so that during any previous epoch the mean temperature must have been higher than it now is. Indeed, if it could be proved that the earth is liable to recurrent periods of greater heat and cold, the entire course of our investigations must have been wrongly directed, and all our conclusions would be swept away.

If, on the other hand, we can show that the phenomena of the Glacial epoch are not necessarily to be accepted as a proof of a generally lower temperature throughout the earth, and that such an assumption increases rather than lessens the difficulties of the glacial problems, we shall be justified in adhering to the views which have been brought forward and upheld in the preceding chapter. This we hope to be able to do, to the satisfaction of all candid minds; and we expect to make it evident that the subject of the climatic relations of the Glacial epoch has been misunderstood, or else its difficulties quite ignored, by most of those who have written on the geology of the period in question. This adherence to our previously expressed views will be proper and justifiable, even if in the course of the discussion it should be made apparent that there are points in regard to which no satisfactory explanation can be offered, provided it can be shown that other and still greater difficulties are forced upon us by the adoption of refrigeration as the sole or principal cause of the phenomena of the Glacial epoch.

If, in the discussion on which we are about to enter, we call upon the reader to admit that in dealing with this subject problems present themselves for which no satisfactory solutions can be found, it may be considered very unsatisfactory, but it will by no means be a new thing in geological science. In the opinion of the writer it has been too much the custom among geologists to overlook the theoretical difficulties which are encountered in the careful study of almost any phase of the past history of the globe. The general adoption of Lyellian views makes things pleasant for the superficial inquirer; but it is quite time that it began to be more fully recognized that "uniformitarianism" is but little better than a delusion, and that at no previous epoch in the world's geological history has the course of events been exactly the same as they were previous to that time or as they will be in the future. A logical carrying out of Lyell's ideas would oblige us to admit that the changes now taking place in the sun are the same as those with which the moon presents us. It is true that the laws of matter and force remain constant through all the ages; but the manner in which they work together to bring about geological results has varied enormously with the earth's changing conditions, and especially those connected with temperature, and they will continue to vary until this planet in its refrigeration has attained the lowest point rendered possible by the nature of surrounding space.

It cannot be too strongly impressed on the student, as well as on the practical worker in geology, that while the collection of facts is comparatively easy, so that already a whole library of them is at hand, the accounting for these — even when they are of the simplest kind — is in almost every case a matter of extreme difficulty. We can, at best, but hint at what may have been the possible conditions under which the various geological changes occurred; and when we ask ourselves whether we fully comprehend the course of events during any, even a very limited, period of the earth's history, we shall, if we are honest, find ourselves obliged to confess that we do not. The more recent the geological epoch to the study of which we apply ourselves, the more we are justified in indulging a hope of arriving at a solution of the theoretical difficulties which present themselves; because the analogy with that which is now taking place will be more complete the nearer the phenomena with which we have to deal are to the present time. Hence it is that "surface geology" has become of late such an attractive subject for the geologist. It seems as if in that which is most recent, and most accessible to investigation, we had some chance of reaching theoretical conclusions of value. Even here, however, the difficulties which present themselves become but too obvious when we consider how little unanimity of opinion there is among those who have of late years occupied themselves most busily with this department of geological investigation.

In endeavoring to throw light on the subject before us, it will be found advisable to adopt the following order in the development of the subject. In the first place the present distribution of snow and ice throughout the world will be briefly considered and described, with so much detail as may be desirable to enable us to form a correct idea of the physical conditions under which precipitated moisture takes the form of snow; how and where it afterwards becomes converted into ice; and why this ice accumulates in certain regions in much larger quantities than in others seemingly not very differently situated.

The next step will be to show, by a statement of what has happened during the past few centuries, even within fifty years, how greatly the dimensions of existing glaciers may vary within a brief space of time, while we are powerless to detect any corresponding climatic changes with which the fluctuations of the ice might be connected. This will enable us to comprehend the possibility of a former much greater extension of snow and ice in certain regions, without the necessity of invoking the aid of violent changes of climate, such as have been demanded by the theories most in vogue among geologists.

Thus prepared for the continuance of our investigation by a knowledge of the manner in which ice and snow are now distributed, and by a demonstration of the fact that the play of forces on which this distribution depends is so delicately balanced that scarcely perceptible variations in their relative preponderance do bring about results of magnitude, we shall proceed to the next branch of the inquiry. Here we shall pass in review the most important of the facts connected with the Glacial epoch. In the course of this review the writer believes that it will be shown that if ice has formerly extended over certain regions where now neither snow nor ice has any permanent lodgment, these areas were of but small size, as compared with the entire land surface of the globe, much the larger part of which remained entirely unaffected by this abnormal glacial development. Such being the case, it seems to follow, as a matter of course, that the phenomena of the Glacial epoch, being local in character, have to be accounted for by combinations of local causes, and not by a general one. After learning something of the conditions required at the present day for the formation of glaciers, the reader will, it is hoped, be prepared to follow the author in his attempt to apply those conditions to the phenomena of the Glacial epoch, and to show that to explain these it is proper to call in the agency of causes which now produce results of a similar character, although perhaps, for the same region, not of the same order of magnitude. In short, for each formerly glaciated region there must be reconstructed the proper set of climatic and topographical conditions which the phenomena there exhibited may seem to demand. This can only be done after all the facts have been thoroughly studied out. It is believed, however, that enough is known already to warrant the assertion that a general refrigeration of the earth could never have caused that peculiar distribution of snow and ice to which the term Glacial epoch is commonly applied; and that the phenomena in question are entirely compatible with a higher mean temperature than now prevails.

Finally, it will be desirable that we should review the various theories which have been proposed to account for "glacial climates," and especially those which look to a recurrence of heat and cold, or at least of conditions favoring the development of ice in abnormal quantity, on the two hemispheres alternately. In the course of this discussion it will become evident that the present writer is by no means alone in his view of the compatibility of a generally higher mean temperature of the earth with a greater extension of ice over certain regions.

SECTION II. — *Present Distribution of Snow and Ice throughout the World.*

In the present section a brief description will be given of the regions which remain throughout the year covered by accumulations of snow or ice. The aim will be to touch on those points which are of especial interest to us as bearing more or less directly on the inquiry in which we are engaged. To go into full details will, of course, be impossible; but it seems necessary to place before the reader a statement, if only a brief one, of certain facts connected with present glaciation on the earth, to which sufficient attention has not heretofore been paid by those geologists who have occupied themselves with this department of investigation. The method pursued will be, first, to present the facts themselves as concisely as possible, selecting from the great mass at our disposal such as seem best fitted for our purpose, and then to comment on the material thus brought together, seeking to arrive at a clear understanding of the climatic and topographical conditions which at the present time appear to favor the formation and growth of glacial accumulations.

In making a rapid review of those portions of the earth's surface where perpetual snow and glaciers are now found, we may begin with the southern hemisphere, leaving, however, the Antarctic Polar region to be taken up a little farther on, and in connection with a description of the glacial conditions of the North Polar area. The reason for this course will, it is presumed, be readily understood when the exceptional character and position of the Polar regions are taken into consideration.

South America may therefore be first mentioned; and in examining that country it will become at once apparent how unimportant a part snow and ice play in its physical geography. All through the chain of the Andes, from the Isthmus of Panama down nearly to the southern border of Chili, there is nothing which can properly be called a glacier system. For this not only is the range too narrow, but its situation within the equatorial belt, or near to it, carries the line of perpetual snow so high that it is only here and there that a few of the higher points project above it. Indeed, until quite recently it was hardly known or admitted that there were any glaciers in the northern portion of the Andes.*

* Humboldt in his "Personal Narrative," when describing the mountain chains of the equatorial regions of South America, never uses the word glacier or ice, but speaks constantly of snow. Indeed, it may be mentioned

Almost all that we do know of the glaciers of the Andes, north of Patagonia, is the result of Mr. Whymper's remarkable explorations of the "Great Andes of Ecuador" made during the season of 1879–80.* The snow line in Ecuador appears to lie at about 16,000 feet; for Corazon, which has an elevation only a hundred or two feet less than that, "hardly enters the snow line." As there are several peaks or cones which rise to nearly 20,000 feet in elevation, and one which surpasses that altitude (Chimborazo, 20,577 feet, according to Whymper; 20,703, Reiss and Stübel), there is of course considerable opportunity for the accumulation of ice or snow around the summits of these great cones. Sometimes ice predominates; at other times, snow. On Chimborazo "the ascent was mainly over snow, and entirely so after 19,000 feet had been passed." On Cotopaxi, next in elevation to Chimborazo (19,550 feet, Whymper; 19,498, Reiss and Stübel), "the whole of the ascent was made over snow, with the exception of the final cone, which was a combination of ash and ice." Of Antisana (19,260 feet, Whymper; 18,885, Reiss and Stübel) it is said that "the western side is almost entirely covered by glacier," the foot of which extends down to 15,295 feet. On Illinissa the foot of the southernmost glacier is at 15,300 feet. Mr. Whymper thus sums up his observations in regard to the glaciers in question: "In general features they present no points of startling difference from the glaciers of Europe. Although on several of the mountains which have been named the glacier-covered area is comparable to the amount on Mont Blanc, the Equatorial glaciers never descend to so low an elevation as one would expect from glaciers flowing out of such extensive reservoirs. I know of no instance of an Ecuadorian glacier descending so low as 12,000 feet, and they generally terminate between 14,000 and 15,000 feet. Moraines are scarce upon them, for the reason that few rocks rise above them, and the evidences which moraines frequently afford of former greater extensions of glaciers is consequently wanting. *Roches moutonnées* are rare, more perhaps on account of the ease with which most of the rocks disintegrate than from any other cause. On the south

as a curious fact, illustrative of the very modern introduction of ice into geology, that neither the word glacier, nor its equivalent in any language, is to be found in Buschmann's extraordinarily copious index to the Kosmos of Humboldt. Even in the very recently published article on Ecuador in the Encyclopædia Britannica, the crater of Altar is said to be "remarkable as the bed of the only real glacier known to exist in the Ecuadorian Andes."

* Of these most arduous and successful explorations hardly anything more than a brief synopsis has as yet been published. See Proceedings of the Royal Geographical Society, New Series, Vol. III. p. 449, and the Alpine Journal, Vol. X. pp. 49–56, 113–122, 185–194, 241–251, 369–377, 425–452, under the title of "Expeditions among the Great Andes of Ecuador."

side of Chimborazo, in a valley in which there is now no glacier at all, was the only place in which I was certain of *roches moutonnées*, but this single instance proved that glaciers on that mountain have formerly extended lower down than they do now."

The glaciers are largest on the eastern sides of these immense cones, as might be expected, since the vapor-laden winds come from that direction. The frozen precipitation wraps the higher portions of the mountains in an envelope, here of ice and there of snow, according as more or less rain falls at those elevations, the high temperatures sometimes experienced at great altitudes in the Ecuadorian Andes rendering it certain that a part of the precipitation must be in the form of rain even at the very summits of the cones. Indeed, Mr. Whymper speaks of being "well-drenched in heavy rain-storms" when encamped at heights of over 15,000 feet. In camp on Cayambe (14,760 feet), much rain and some snow fell during the night. Heavy rain is mentioned also * between the Haciendas of Antisana and Antisanilla (13,300 feet).

Of the snow and ice conditions on the Peruvian Andes little is definitely known. The examination of various excellent photographs of the higher points of that portion of the country indicates the absence of anything like well-formed glaciers. Usually the depressions and ravines around the very summits are seen to be more or less filled with snow, but nowhere do portions descend much below the general level of the lower edge of the snow mass, as would be the case were there large glacier systems present. Indeed, it is not to be expected that such would be formed around these isolated volcanic masses, for their conical form precludes the existence of large gathering-grounds, in issuing from which the ice currents may be sufficiently powerful and well-developed to make their way down to a level much lower than that of the ordinary snow line.

In the Andes of Northern Chili, in spite of their great elevation and their higher latitude, there are, according to Pissis, no glaciers. The climatic conditions seem to resemble in a marked degree those of the Sierra Nevada of California. The amount of precipitation is large; but it is all in the winter, and in the form of snow. In the summer the air is exceedingly dry, and the melted snow is all evaporated from the surface and does not sink in so as to form ice. Hence, as seen in the numerous excellent photographs of

* On Antisana, for instance, during the two hours spent on the summit, the thermometer ranged between 44° and 60° (F.).

those mountains, the snow lies in masses which vary greatly in size from year to year, according to the variability of the seasons or of a succession of seasons, just as is the case in the Californian range.*

Pissis remarks,† that in going south along the Andes the first glaciers are seen in the province of Colchagua, and that the most remarkable of these is that from which issues the Rio de los Cipreses. The ice here descends to a point 5,850 feet above the sea-level.

Proceeding southward from Colchagua, we pass into a region in which the climatic conditions are very different from those prevailing in the country farther north. The ranges border the sea very closely, the amount of precipitation increasing and becoming more generally distributed throughout the year. The temperature, at the same time, diminishes, and all the conditions favorable to the formation of glaciers are found to prevail. In consequence of this there is an extensive display of snow and ice along the southern coast of Chili, and especially at the very extremity of the continent. According to the measurements of the officers of the Beagle, the culminating peaks between latitudes 41° and 43° 30′ are from 5,600 to 7,500 feet in height. On these the snow in February (answering to our August) descended to 4,480 feet above the sea-level, "presenting to a distant beholder a perfectly horizontal line." In Chiloe (lat. 41°–43°) the elevation of the snow line is given by Darwin at 6,000 feet; in Tierra del Fuego (lat. 54°), at 3,500 to 4,000 feet. He remarks as follows in regard to the glaciers of that region: "In Tierra del Fuego the snow-line descends very low, and the mountain sides are abrupt; therefore we might expect to find glaciers extending far down their flanks. Nevertheless, when on first beholding, in the middle of summer, many of the creeks on the northern side of the Beagle channel terminated by bold precipices of ice overhanging the salt water, I felt greatly astonished. For the mountains from which they descended, were far from

* Mr. Darwin, in his "Journal and Remarks" forming a part of the Voyage of the Beagle (pp. 277 – 278), makes the following statement, which is of interest as connected with what has been mentioned above in regard to the varying amount of snow in the Chilian Andes: "I have reason to suspect that the snow-line in Chile is subject to extreme variation. I was told that during one remarkably dry and long summer, all the snow disappeared from Aconcagua. . . . . It must be remembered that even in ordinary summers the sky is generally cloudless for six or seven months, that no fresh snow falls, and that the atmosphere is excessively dry. It may be asked whether vast quantities of snow would not, under this condition of circumstances, be evaporated? so that it might be *possible* that all the snow should disappear from a mountain without the temperature having risen above the freezing point. Mr. Miers (Vol. I. p. 384) says he passed the Cordillera by the Cumbre Pass on May 30th, 1819, 'when not the smallest vestige of snow was observable in any part of the Andes.' Yet Aconcagua is in full view of the approach to this pass. Mr. Miers, in another part (p. 383), makes a general assertion to the same effect."

† Descripcion topografica i jeolojica de Colchagua, in Anales de la Universidad de Chile, XVII. 703.

being very lofty." * These mountains appear to be from 4,000 to 7,000 feet in height, and the whole coast, as seen in various photographs examined by the present writer, is exceedingly precipitous. The extraordinary change in the conditions with regard to the occurrence of snow and ice presented along this coast, in passing over not much more than ten degrees of latitude, is evident from what has been here stated. On Aconcagua, the elevation of which is not far from 22,000 feet, no glaciers exist and the snow sometimes disappears entirely; Corcovado, on the other hand, rising in an unbroken slope close to the sea to a height of 7,500 feet, appeared to be permanently snow-covered for at least one fifth of its visible perpendicular height. The difference of latitude between the two peaks is about the same as that between the southern end of the Sierra Nevada and Mount Rainier.

It is not, by any means, all of Tierra del Fuego and the adjacent coast of South America which is covered with snow and ice. Most of the island is a "broken mass of wild rock, lofty hills, and useless forests." In the Beagle channel it is the lofty mountains on the north side, composing the backbone of the whole country, over which is spread a wide mantle of perpetual snow, and from which glaciers extend to the water's edge.†

Africa, with its eleven millions of square miles of surface, has, so far as known, no regular glaciers, and only a few spots covered with eternal snow. Kilimandjaro, a peak nearly 20,000 feet high, situated only three degrees south of the equator, has near its summit a considerable area of snow. The same is reported of a peak called Namuli, in the Makua country, in about 14° south latitude.‡ The elevation of the snow line in that region would be about 16,000 feet.

The only really interesting and important glacier region in the eastern hemisphere, south of the equator, excluding the Antarctic Polar ice fields, is in New Zealand. Here, on the western coast of the southern island, between the parallels of 42° and 45°, rises abruptly from the sea a grand range of mountains, the culminating point of which, Mount Cook, is about 13,000 feet in elevation. Along this chain, for a length of about a hundred miles, are developed numerous groups of glaciers, some of which are not much inferior in size to the largest of those of the Alps. The Tasman glacier is said by Haast, who first scientifically explored and described these mountains, to be

* Voyage of the Adventure and Beagle, Vol. III. p. 280.

† l. c., p. 243.

‡ See Proceedings of the Royal Geographical Society, New Series, Vol. IV. p. 211.

ten miles in length and a mile and three quarters broad at its termination, the lower portion, for a distance of three miles, being covered with morainic detritus.* The climatic conditions of the region where these glaciers occur will easily be understood when we call to mind its peculiar position with reference to the prevailing westerly winds blowing across the warm South Indian Ocean.† The amount of erosion caused by the abundant precipitation, as described by Haast, is indeed remarkable. Mountains of from 5,000 to 6,000 feet in elevation have piled up against their flanks masses of gravel thousands of feet in thickness, the terraced character of which indicates — to the present writer, at least — most clearly the gradual diminution of the amount of precipitation in later geological times. We have in these detrital masses of New Zealand the exact parallel of the "washes" of the Great Basin Region.‡

The Asiatic continent may well be considered as likely to throw light on all points connected with either present or past glaciation. Having an area greater than that of North and South America combined by nearly two and a half million square miles, being in fact much the largest land mass of the globe, —Europe proper seeming but a mere diminutive appendage to it,—we naturally turn thither with the expectation of finding illustrations of every kind of climatic condition possible under present circumstances. This vast mass of land extends from the equator to beyond the 75th parallel of latitude, and embraces every variety of surface, including the most complicated mountain systems, the highest summits, the most elevated and extensive table-lands and the grandest plains of the globe. Its lofty chains are developed in almost unbroken sequence from the Tropics to the Arctic Circle. It would seem, therefore, impossible that any phenomenon affecting the earth in general should not have manifested itself over some part of this continental mass. Hence, if we seek to determine whether there has once been a Polar ice-cap covering a portion of the northern hemisphere, or a period of general glaciation not proceeding from the Polar regions, or, in fact, any great change, or series of changes, in the climatic conditions of the earth from epoch to epoch, it is to Asia that we seem to be most fully authorized to turn for evidence bearing on the question brought up for investigation, and

* See Neu-Seeland, by F. von Hochstetter, Stuttgart, 1863, p. 348.

† Mr. I. C. Russell, in the Annals of the N. Y. Lyceum of Natural History, Vol. XI. p. 252, gives the rainfall at Hokitika, on the West Coast, from May to December, 1856, at 96.082 inches; at Christchurch, on the eastern side of the mountains, during the same period, it was only 17.395 inches.

‡ See *ante*, p. 36.

we should expect to be very largely guided in our conclusions by the facts there presented. What we have first to do, in pursuing our inquiry over the Asiatic region in accordance with the order followed in the present chapter, is to show where and under what conditions ice and snow occur at the present time over the various divisions of that continent; and that this may be done understandingly it will be desirable, as a preliminary, to give a rapid sketch of the topographical features of the great Asiatic land mass, with especial reference to those conditions likely to affect the amount and character of the precipitation so unequally distributed over its surface. Imperfectly known as portions of Asia still are, it is believed that enough has been found out with reference to the topography and climatology of that country to enable us to deal with the most general and important questions arising in this connection.

The continent of Asia may be considered, from the most general point of view, as made up of two parts — a central elevated portion, and a lower region — both of which cover areas of enormous extent, as compared with the entire land mass of the globe. The higher region is soon perceived, on examination, to be made up of a series of high plateaux, each framed in by a border of mountain chains. These table-lands are so closely connected with each other, and the various lofty ranges which encircle them so linked together, that the whole stupendous mass of mountains and plains can hardly be looked upon otherwise than as forming a geographical unity. Indeed, the name "High Asia," in which term far the larger portion of the elevated mass of the continent is comprised, is already current among geographers. The Iranian and Arabian plateau systems, with their enclosing and bordering ranges, spreading themselves to the westward in Asia Minor, are so closely compacted with High Asia by inosculating chains of mountains, that the entire complex is clearly seen to belong together, and to form the central nucleus, which, stretching from the Red Sea to the Northern Pacific, or from southwest to northeast, constitutes by far the grandest highland system of the world, of which the mountain regions of Europe are in reality but diminutive appendages.

Of the Arabian and Iranian table-lands and mountain chains we have nothing to say in this connection, since they are not sufficiently elevated to reach the region of eternal snow. Their increasing dryness has already been the subject of comment in the preceding chapter. Of two mountain ranges, however, one of which is entirely isolated from the elevated central highland and the other nearly so, it will be desirable to say something before proceeding to consider the grander and more complicated features of High Asia itself. These ranges are the Caucasus and the Ural, two chains so distinct and well marked in geographical position as to be easily separated from all others. The Ural is especially an independent chain, disconnected with any other system of mountains as well by its meridional direction as by its isolated character; while the Caucasus, abutting at its two extremities on the Black and Caspian Seas, is so far removed by these depressions from the great line of elevations of Central Asia and Southern Europe of which it in reality forms a part, as to be most easily limited on all sides. All the other Asiatic chains are so connected with the great central mass of that continent as to be only with difficulty separated into precisely limited groups.

Both the Caucasus and the Ural form links in the partly artificial and partly natural boundary-line between Europe and Asia. The first mentioned has many features in common with the Alps, and it might with propriety be considered a part of the great mountain system of Southern Europe. These ranges lie nearly within the same parallels of latitude, and their average elevation is not very different. The western end of one abuts squarely on the Black Sea; that of the other curves around to meet the Mediterranean. The Caucasus rises quite abruptly from its base, and forms a somewhat narrower and more compact mass than that of the Alps. Taking these facts into consideration, it will be apparent that a considerable similarity in the present glacial character of the two ranges is to be expected. This is indeed the case, as is shown by the statements of the various geological explorers of the Caucasus, especially Abich, who has devoted so many years of labor to that chain. The Alpine glaciers are more numerous, and in most cases extend to a greater length than those of the Caucasus, since the abruptness of the latter chain is unfavorable to the development of those high plateaux and vast *cirques* which only can give birth to masses of ice like those of the Gorner and Aletsch. Owing partly to the simplicity of structure and compressed form of the Caucasus, and partly also, as appears probable, to purely climatic conditions, the glaciers in this range do not descend to a very low level. By far the most important snow and ice masses of the Caucasus are in the central portion of the range to which the grand peaks of Elbruz (18,572′), Koschtantau (17,123′), Dychtau (16,928′), and Kasbek (16,546′) belong. The average height of this portion of the chain along a length of about 120 miles is fully 12,000 feet, and it is here only that glaciers which rival the largest of the Alps can be found. That of Kaltschidon, for instance, is nearly five miles in length, and this one descends to a lower point (5,702 feet) than any other in the range. The average elevation of the ends of the principal glaciers descending from Elbruz is 8,216 feet. In the Alps, on the other hand, the lower limit of the great ice masses is much below that.

The snow line on this range is given for the north slope at a little over 12,000 feet, and for the south side at about 11,000 feet. The elevation of the snow line in the Caucasus varies considerably in different parts, as might be expected when we consider the climatic conditions which necessarily prevail in a chain the eastern and western portions of which are so differently situated with reference to those causes which influence precipitation. It is higher on the northern slope, because that is the drier side, a similar condition of things revealing itself, on a larger scale, in the Himalaya. The difference in the Caucasus is on the average fully a thousand feet. The glaciers on the northern slope, on the other hand, descend considerably lower than they do on the opposite side of the range. This is due to the fact that the large gathering-grounds of the *névé* are on the northern side, the topographical features on that slope more resembling those of the Alps than they do on the other.

The glacial conditions of the Ural are quite remarkable, since although this range extends beyond the Arctic Circle, with a considerable elevation, it has no glaciers or even what might properly be called perpetual snow. The range is commonly divided into three portions — a southern, central, and northern. Of these the latter may be taken as beginning at the head-waters of the Petschora River and extending to latitude 68° 30′. This part of the Ural has the regular north and south trend of the range, and its culminating points rise to elevations of from 3,000 to 5,000 feet. But even these high peaks do not appear to have any glaciers formed around them. Snow is said to lie in the sheltered gorges through the summer, and in masses of considerable size; but, on the whole, the range is remarkably free from it. The conditions in fact are, in this respect, so peculiar that it will be worth while to quote what Dr. E. Hoffmann, the chief of the official exploration of the Northern Ural, has to say in regard to the absence of glaciers and permanent snow in this range: "The mean elevation of the high points [Gipfelhöhe] of the entire Northern Ural may be taken at 3,000 feet. Although several peaks which are north of the limits of the Arctic Circle exceed this elevation by some hundreds of feet, yet not one reaches the line of perpetual snow. Patches of snow [Schneeflecke] remain on many of the mountains through the whole summer, but not one of them has a permanent snow covering. In Norway, according to Wahlenberg, the snow line is reached, between the parallels of 67° and 67½°, at 3,800 feet, and according to L. von Buch, between 70° and 71½°, at 3,300 feet; on the coast in fact, in 71½°, it is found at 2,200 feet. It cannot therefore but appear strange that in the Ural, in latitude 68°, not far from the shores of the Arctic Ocean, from which in summer, whenever a north or northwest wind blows, thick fogs and cold are spread over the Gnetja and its vicinity, the snow does not remain permanently [nicht halten kann] although covering the adjacent tundra to the depth of several feet, while the thermometer often sinks below the freezing-point of mercury. The reason may perhaps be found in the narrowness of the chain, which on both sides rises from the tundra with precipitous walls, terminating in sharp peaks and pinnacles."*

Even the Pae-Choi range which extends in a northwesterly direction from the northern extremity of the Ural, and is prolonged on the island of Nova Zembla, is free from permanent snow and glaciers, although it lies beyond the Arctic Circle, and rises to an elevation of a thousand feet and more.

We turn now to the consideration of the great elevated mass of Central Asia, where, active as have been the geological and geographical explorations of the past few years, much yet remains to be done before the structure and relations of the various mountain chains and plateaux are fully made out. The systems of ranges of which a brief notice will here be taken are, in fact, portions of the exterior rim of this vast elevated area, and it is, in general, only these outside regions of which something is known in detail. Of much of the interior, and especially of the part which borders on the western confines of China, almost nothing has as yet been made out, except in roughest outline.

The southern edge of the elevated region of Central Asia is formed by the Himalayan ranges, which in several parallel folds sweep in a majestic curve from the east towards the northwest. Between these folds, and occasionally breaking transversely across them, flow the three great rivers of India,—the Indus, the Ganges, and the Brahmapootra. At the northwestern extremity of the Himalayan ranges the Pamir Plateau forms a grand nodal

* Der nördliche Ural, und das Küstengebirge Pae-Choi. Untersucht und beschrieben von einer in den Jahren 1847, 1848, 1849, und 1850 durch die Kaiserlich-Russische geographische Gesellschaft ausgerüsteter Expedition. 2 Bände, 4to. St. Petersburg, 1856. Band II. pp. 191, 192.

point, — the so-called Roof of the World, — where the northwest-southeast direction of the Indian ranges ceases, and the Himalaya may be said to terminate. Here commences an extensive group of elevations, forming the western edge of the great Central Asiatic mass, and extending as far north as the forty-fifth parallel, the dominant direction of the ranges being a little north of east and south of west. Southwest of the Pamir Plateau, ranges having the same direction, and being in fact part of the same system, are grouped under the name of the Hindu-Kush; to the north they are embraced under the collective name of Thian-Schan, or Celestial Mountains. These lie chiefly between the fortieth and forty-fifth parallels, and extend over more than thirty degrees of longitude (from 65° to beyond 95°). On the northeast of the Thian-Schan the Djungarian Basin forms a pretty marked line of separation between that group of ranges and another one with a southeast-northwest trend, known as the Altai, and forming an important part of the northern edge of High Asia.

Beyond the Altai, stretching to the northeast and becoming more and more nearly parallel with the coast of the Pacific, is a vast labyrinth of mountains — the Jablonovoi and Stanovoi ranges — occupying the space between the Amur and the Lena, and extending even beyond, far towards the northeastern extremity of Siberia.

While the Himalaya, the Thian-Schan, and the Altai may be considered as being pretty well known, a large portion of the vast area enclosed within these exterior ranges has as yet been but little explored. Its main feature may be said to be a stupendous chain of mountains which, beginning at the nodal point of the Pamir, extends eastward for about 2,000 miles, and is known as the Kuen-Luen. This range, the importance of which as a topographical feature of Central Asia was first indicated by Humboldt, and since demonstrated by Richthofen,* begins at the west in a single mass, and gradually acquires complexity, by the development of parallel members, forming in fact, as Richthofen considers, the real backbone of the eastern half of the continent.

The range of the Kuen-Luen has on its southern side, enclosed between it and the Himalayan chain, the high Tibetan table-land, the Highland of Khor, the most elevated plateau region of the world — a closed basin, with many salt lakes, cold, dry, and desolate. To the north of the Kuen-Luen, between that chain and the Thian-Schan, is the Tarym closed basin region,

* China, Vol. I. pp. 223 - 272.

once in large part occupied by water,* and of decidedly lower elevation than the Khor Plateau.

In all of the explored region of mountain chains forming the borders of the Central Asiatic mass, the distribution of snow and ice is strictly subordinated to those physical laws which have already been discussed in this volume. The chain which is nearest the tropics, at whose southern base no snow ever falls, but where during most of the year the heat is intense, is the one where the glaciers are most extensively developed: some occurring there are much larger than the grandest of the Alps themselves. As we penetrate farther in towards the centre of the elevated region, we find ranges of immense elevation, regions of intense cold, and all the requisites for extensive glaciation, except the most essential one of all, abundant precipitation. Chains of mountains rising to more than 20,000 feet in height are only sparsely covered with snow at their very summits; large glacier systems are wanting altogether; and the snow line rises higher and higher — not that we are approaching warmer regions, but because we have come to parts of the country from which the precipitation has been almost entirely cut off by the exterior ranges of mountains. Although we seem to have in Central Asia all of those conditions which are considered by most geologists as essential to the development of extensive glaciation, yet the facts prove, beyond possibility of doubt, that this region of very low mean temperature is by no means generally glaciated, but that, taken as a whole, with the exception of the southern border — which is exceedingly high and faces prevailing winds characterized by extreme moisture — the occurrence of snow and glaciers is something very exceptional, and confined, as a rule, to the higher portions of the highest ranges. A few facts may be cited as illustrative of the truth of this statement, which might be supported by a much longer array of them.

In Leh, in Thibet, at an elevation of from 11,000 to 12,000 feet, so dry is the climate that there are winters when no snow falls. At the same place and in Lassa there are years when the entire amount of precipitation does not exceed one inch.†

Dr. Henderson remarks as follows in regard to the region traversed by him after crossing the Himalaya, in going from Lahore to Yarkand: "The line of perpetual snow in Ladak is probably not under 20,000 feet. On

* See *ante*, pp. 132, 133.

† Hermann von Schlagintweit, in Reisen in Indien und Hochasien, Jena, 1872, Band III. p. 312.

entering Ladak from Kashmir the climate and appearance of the country completely change. The pine-clad mountains and densely wooded valleys are replaced, as we have seen, by an apparently endless succession of barren rocky mountains and valleys, which are almost desert except along the margins of the streams. . . . . Wherever the mountains rise to about 20,000 feet they are covered with perpetual snow. . . . . Rain scarcely ever falls in Ladak. I believe it is no exaggeration to say that the entire rainfall for twelve months would hardly be sufficient to wet one's coat. Captain Strachey estimates the total amount of rain and snow at about three or four inches. Snow occasionally falls to the depth of six or eight inches at one time, but owing to the excessive dryness of the atmosphere, it usually evaporates in a few hours without perceptibly liquefying."*

The pass by which Dr. Henderson crossed the Kuen-Luen range was about 16,600 feet in height. Here no snow was observed in going to Yarkand, but on the return journey "wreaths of snow were observed on the pass." The range itself as seen from a distance, and when estimated to be about 25,000 feet in height, was observed to be "tipped with snow." Farther east is the Kuen-Luen range, on the borders of China. Prjewalsky found no permanent snow at an elevation of 5,000 meters (16,400 feet).†

In the Karakorum range Hayward crossed a pass having an elevation of 17,710 feet, which at the time was entirely free from snow. Many of the adjacent summits, which rose to 18,500 feet and over, were also bare.‡

The Pamir is in reality not a simple plateau, but a series of more or less level tracts separated by high ranges, having a decided parallelism with those of the Thian-Schan. The elevation of the more level portions of the Pamir seems to be from 12,000 to 15,000 feet, and there are many points in the ranges built up on it which reach, or even surpass, 25,000 feet. In spite of this great elevation, a large portion of the region seems free from snow during a part of the year. Gordon says that there are trails across it in all directions, and that with a guide one could traverse it in almost any place.§ This, however, is not possible except in summer, for it is only then that the ground is bare.

In the map of the Pamir Plateau and the neighboring portions of the

* Dr. Henderson, in Lahore to Yarkand, London, 1873, pp. 62-65.

† Richthofen, China, Band I. p. 265.

‡ See "Ost-Turkestan und das Pamir-Plateau," in Ergänzungsheft to Petermann's Mittheilungen, No. 52, 1877, p. 37.

§ In "The Roof of the World," quoted in Reclus, Géographie Universelle, Tome VI. p. 320.

Himalaya, Thian-Schan, and Hindu-Kush, compiled by Petermann from all materials accessible up to 1877, the position of the glaciers is given as far as known. These are represented as numerous and of great extent, all along the Himalaya, following the ranges towards the northwest, as far as the head of the Indus, in the region embraced between the 36th and 37th parallels and the 73d and 74th meridians (Greenwich). Of the Himalayan glaciers notice will be taken farther on. To the north and northwest of the head-waters of the Indus, but very few glaciers are indicated on this map. There are several, however, of considerable size around some of the very highest peaks. For instance, at the eastern edge of the Pamir, in the Kisil Yart range, which has a direction nearly at right angles to the trend of the Thian-Schan, is the Tagharma, rising probably to a height greater than that of Mont Blanc by nearly 10,000 feet.* This mountain mass is also called by a name which signifies "Father of Ice Mountains," and it well deserves the name, since it is said to be capped with eternal snow from which descend large glaciers in all directions.

At the northwestern angle of the Pamir are two grand mountain chains, known as the Alai and the Trans-Alai, which have the same trend as the Thian-Schan range proper, to which they appear really to belong. These are very lofty ranges having points upon them nearly 25,000 feet high,† capped more or less extensively with eternal snow, and with glacier systems of great magnitude. Indeed, the southwestern portion of the Thian-Schan is more favorably situated with regard to moisture-bearing winds than the higher region to the southeast, and portions of this range, which probably exceeds in extent and elevation all the mountain chains of Europe taken together, are extensively glaciated. There is, however, but little known in regard to the details of its snow and ice masses. The glacier system at the head of the Musart and that of Khan-Tengri (King of the Heavens) are the most celebrated. The dominating peak of the former system is said to be nearly 20,000 feet in elevation. To the west of this is a region where the chain, for a distance of sixty or seventy miles, has a mean elevation of over 16,000 feet, many high points surpassing Mont Blanc in altitude by more than 3,000

* The elevation of Tagharma is given by Kostenko at 7,775 meters (25,500 feet). It is put down on Petermann's map as 25,350 feet high.

† According to Fedtschenko, Mount Kaufmann, in the Trans-Alai, is 7,500 meters (24,600 feet) high; Ochanin gives the same elevation to Chelveli and Sandal. The snow line in Trans-Alai is given by Fedtschenko at 14,000 feet.

feet. Some of the glaciers of this region are said to have a length as great as that of the longest in the Alps.

The mountain system of the Altai is much less extensive than that of the Thian-Schan; still it is a range of importance, being comparable with the Alps in magnitude, and having formerly been a mining region of great productiveness. The western flanks of the Altai are steppe-like in character, for the prevailing southwesterly winds have before reaching them become completely dried of their moisture. The northeast winds, on the other hand, although cold, do bring refreshing and fertilizing rains to the slopes on that side of the range. The mean elevation of the Altai is not as great as that of the Alps, hardly exceeding 5,000 feet. The highest point has an elevation of about 11,000 feet, and around this there are perpetual snows, and a glacier of over a mile in length.

It is not possible to go into fuller details in regard to the present glaciation of the northern and northeastern sides of High Asia. Enough has been said, it is believed, to show clearly how entirely dependent on climatic conditions is the distribution of snow and ice all through that vast area. It cannot fail to have become apparent to the reader that however low the mean temperature of a great mountain region like that of Central Asia may be rendered by its extreme altitude, it will not be covered with perpetual snow, or much less with anything resembling a general ice-sheet. The exterior ranges will receive the bulk of the precipitation, and only the very summits of the highest chains, inside the mass, will be tipped with eternal snow. No doubt if the high area were large enough its interior would be entirely bare of snow, no matter how elevated it might be. As illustrative of how snow and ice collect, where the climatic conditions are favorable, even in close proximity to regions of high mean temperature, a few words may be added in regard to the magnificent glacier systems of the Himalayas. Here, and especially on the southern slopes of that range, as has already been explained,* the precipitation is very large, the winds prevailing during a large part of the year sweeping across the heated waters of the ocean to the south, and carrying the moisture thus collected to be deposited on the flanks of the mountains which rise to bar their passage.

In that portion of the Himalayan ranges which lies at the head of the Indus, or the northwest-southeast trending division of the whole mass, the distribution of the snow and glaciers has been carefully studied by Mr. Drew,

* See *ante*, pp. 199, 200.

and a synoptic map of the region has been published by him, compiled from the work of the Great Trigonometrical Survey. From this map an excellent idea can be obtained of the way in which the height and position of the various groups of ranges cause these to be more or less covered with snow and ice-fields. The great plain of the Punjab, which lies at the base of this portion of the Himalayan ranges, is never snowed upon, its mean temperature being very high. It is not until an elevation of some 4,000 feet is attained that snow falls, even in the coldest month of the year. At an elevation of 6,000 or 8,000 feet the precipitation in the form of snow is considerable in quantity, but it hardly remains longer than a few hours, except in the very highest portions of that belt.

Proceeding towards the interior of the range, and having risen on to the Panjal Mountains, which border the Valley of Kashmir on the south, and of which the dominating peaks are from 15,000 to 15,500 feet in elevation, we find still no glaciers; but a little farther to the northwest, where there are points reaching 17,000 feet, small ice masses do exist. In the ranges which lie next farther north, and form the water-shed between the Jhelam and Shayok on one side and the Indus on the other, there are numerous and large glaciers, beginning on the northwest with those developed on the flanks of Nanga-Parbat, which is nearly 27,000 feet in height. In the higher portion of this group, in which there are peaks of from 21,000 to 22,000 feet in elevation, there are extensive snow-fields and ice-flows. Much larger ones, however, occur in the series of elevations forming the Turkestan water-shed, where are peaks second only to Gaurisankar itself — among them the "K^2" of the Trigonometrical Survey, 28,265 feet in height. Here, as Mr. Drew remarks, "the mountains are the most lofty, and the glaciers they give rise to the largest, in the world." One of the grandest of these is at the head of the Basha River, its terminus being at Arandu, between 10,000 and 11,000 feet in elevation. This glacier is over thirty miles in length, its lower part, for a distance of twenty or twenty-five miles, being about a mile and a half in width; above this — for some distance at least — it is still wider. A marked feature of this glacier seems to be its very small inclination; along a large portion of its course it has an angle of slope of not over $1\frac{1}{2}°$ or $2°$.*

At the head of the Braldu valley, an easterly tributary of the Shigar, is one of the largest known glaciers — that of Baltoro. This is said by the

* The Jummoo and Kashmir Territories. A Geographical Account. By Frederick Drew, London, 1875, pp. 366, 367.

officers of the Survey to be thirty-five miles in length,* "measured along a central line from its termination up to peak K^6." The Biafo glacier, the foot of which is about ten miles west of the Baltoro, is said to be over forty miles long.

It is impossible to go into a detailed description of the glacial system of the Himalayas as developed at the heads of the Sutlej and the Ganges. Reference may be made to some of the accessible works, more or less popular in character, where these are described.† Through the whole length of the range there is a constant repetition around the higher masses of great snow-fields with extensive glaciers dependent from them.

The height of the snow line on the two sides of the Himalayan Range is given by H. von Schlagintweit as follows.‡ For the south side of the Himalayas from Bhutan to Kashmir, with a mean temperature of 0°.5 (C.), 16,200 feet; on the north slope, mean temperature —2°.8, 18,600 feet; on the Karakorum Range, in Tibet and Turkestan, between the parallels of 28° and 36°, with a mean temperature of —3°.9, 19,100 feet.

The glaciers of the Alps are so well known, and have been so often described in both popular and scientific works, that it will only be desirable here to recall the more important facts connected with their occurrence.

The smallness of the area covered by perpetual snow and ice in the Alpine chain is the first fact which claims our notice. Switzerland itself has an area of about 14,000 square miles, of which nearly one-eighteenth is thus occupied. The principal glacier districts are, according to Desor, fourteen in number, beginning on the west with that of Mont Pelvoux in Dauphiny, and ending on the east with the snowy range which extends from the Krimmler Tauern to the Heiligenbluter Tauern and culminates in the Gross Glockner. To the east of this there are no snow-fields of any importance on the range.

* l. c., p. 370, and Journal of the Royal Geological Society, 1864, pp. clxiii and 19-56. In the latter paper Captain Godwin-Austen has given a somewhat detailed account of the glaciers of the "Mustakh Range," including those of Biafo and Baltoro.

† The Abode of Snow, by Andrew Wilson, London and Edinburgh, 1875, describes some of the glaciers in Spiti, at the head of the Chandra, a branch of the Indus.

Reisen in Indien und Hochasien by Hermann von Schlagintweit, 4 vols. 8vo, Jena, 1870-1880, Vol. II. contains a chapter (pp. 256-267) on the snow and ice summits of the east-west portion of the Himalayas (Bhutan, Sikkim, and Nepal).

The views taken by Shepherd and Bourne of Calcutta embrace a wide range of the glacier regions of the Himalayas, and are most admirable specimens of the photographic art.

‡ l. c., Band IV. p. 522. It will be seen how the snow line rises with a diminution of the temperature, instead of falling, the necessary result of the diminished precipitation in going towards the interior of the mountain system.

It is not until we reach the Caucasus, in travelling east, that we come again upon perpetual snow.

The most important of the glacier systems of the Alps are those grouped around Mont Blanc, Monte Rosa, and the so-called Bernese Oberland. The culminating points of these are Mont Blanc, 15,784 feet; Monte Rosa, 15,217, and the Finsteraar Horn, 14,026. The area covered by snow and ice in the Bernese Oberland is somewhat more than a hundred square miles in extent. Here is the largest glacier of the Alps, that called the Aletsch, which has a length of nearly fifteen miles with an average breadth of fully one mile. The Mer de Glace of the Mont Blanc system is about eight miles in length, reckoning from its termination below to the crest of the range at the head of the Glacier du Géant.

The height of the snow line on the Alps is given by H. von Schlagintweit at 9,200 feet for the southern side, and 8,900 for the northern. The mean temperature at that line is stated, on the same authority, to be —4° (C.). Where the topographical conditions are favorable — that is, where there is a large gathering ground, the precipitation of which must all be conveyed away in one channel — there the glaciers are longest and reach nearest to the sea-level, as a glance at the various detailed maps of the Alpine glacier regions will instantly show.* Thus the termination of the Mer de Glace is given on Forbes's map, published in 1843, at 3,667 feet above the sea-level. Several of the Alpine glaciers come down to about 4,000 feet, while, as already mentioned, those of the Caucasus do not usually descend much below 8,000 feet, for reasons which have been already explained.

The glacial system of the Pyrenees is very much less important than that of the Alps. There are several reasons for this. One important one is, that the absolute elevation of the range is lower, its culminating point, Néthou, reaching only 11,167 feet. Besides this, the Pyrenees form a chain of great simplicity of orographic structure, so that its breadth is very small compared with its length. Hence there are no such great gathering grounds for the glaciers as there are in the Alpine range. Again, the precipitation is less, and especially on the south side of the chain. In consequence of these combined conditions the ice fields rarely have the longitudinal extent of even the smaller Alpine glaciers. To use the words of a careful explorer of the range, "they are, rather, great irregular and undulating surfaces covering the slopes or the summits, but without descending and winding through the

* See for the Mont Blanc district the beautiful map of Viollet-le-Duc (Paris, 1876).

valleys or the mountain gorges, and not even approaching the upper limit of the pines."* The largest of these ice-fields is on the north slope of the range, a few leagues southwest of Bagnères de Luchon.

Our attention may next be turned to the Scandinavian Range, of which a brief account will here be given, with special reference to the accumulations of snow and ice by which it is partly covered. This region is of great importance, because it has, in former times, been much more heavily occupied by glaciers than it now is, as will be noticed farther on.

The mountains of Norway rise quite directly and precipitously from the sea, along the whole extent of that country — a region of high northern latitude, since it extends to beyond the parallel of 73°. Situated as this range is, in a position to receive the large precipitation resulting from the impact of the prevailing westerly winds blowing across the ocean surface, and impinging against the opposing precipitous mountain sides, it would be expected that, if the elevation of the range were sufficient, glaciers would be extensively developed over its higher portions, and this is, in fact, the case.

The Scandinavian Range differs very much from the Alps, and still more from the Pyrenees and Caucasus, in being throughout nearly its whole extent broad and plateau-like on its summit. Its highest point, Galdhöppigen, reaches an altitude of 8,400 feet; but the mean elevation of the water-shed of the range is considerably less than that. It lacks therefore the altitude necessary for the grandest development of the glacial masses. Along portions of the coast, as about the Hardangerfiord, the cliffs rise very precipitously to the height of 5,500 feet above the water. In Nordland and Tromsö they reach 6,000 feet and over. The deep fiords which extend far into the interior — sometimes to a distance of fully 200 miles — are a characteristic feature of the country.

In all Norway there are said to be twice as many square miles of surface covered by ice and snow as there are under cultivation. More than two thirds of the country are reckoned as "fjeld," — that is, high table-land, not inhabitable, and much of it swampy. About one-fifth of the surface is covered by forests; and one-fiftieth belongs to the region of eternal snow and ice.

The glacial accumulations of the Scandinavian mountains are somewhat different from those of the Alps, a fact due — in part at least — to the marked difference in the topography of the two ranges. In Norway a high

* Henry Russell, in Annuaire du Club Alpin Français, Première Année, p. 19.

plateau-like area is occupied by snow, or snow passing into the condition of *névé*, and from the edges of the mass down through the gorges and valleys leading to a lower level the glaciers descend, sometimes in great numbers, from one continuous mass of *névé*.* The largest of these is that of Justedal, which rests on a high plateau separating the Sognefiord from the more northern districts of the Söndfiord and the Nordfiord. The elevation of this plateau increases from the southwest towards the northeast, and is from 4,600 to 5,400 feet above the sea-level. The culminating summit upon it is Lodalskåbe, 6,811 feet in elevation; others are from 5,600 to 6,400 feet. The entire area occupied by the Justedal snow (or *névé*) mass and the glaciers which are connected with it is estimated at 580 square miles, or more than five times as much as the whole glacier system and snow area of the Bernese Oberland. Twenty-four glaciers of the first class and hundreds of smaller ones carry the accumulating snow down to a lower level. The large glaciers descend to the bottom of the valley towards which they move, and do not originate except where there is a deep gorge or valley leading into the heart of the mass. The snow on the plateau is described by Professor Sexe as having a granular structure; in fact it is *névé*, and is so called in his description.† The largest glacier issuing from the Justedal *névé* is that of Lodal, which descends from the Lodalskåbe, and from Snehætten, a point a few miles farther south. In its widest part this glacier has a development of nearly 4,000 feet; its length is about five miles.

Fondalen is another of these snow-covered plateaux, nearly equal in size to Justedal. It is, however, considerably farther north — in 66° – 67°, namely — and from it the glaciers are said to descend to the sea.

Still another *névé* field is that of Folgefon, which occupies a plateau at an elevation of about 5,000 feet, and has an area of somewhat less than a hundred square miles. From it descend three glaciers of the first rank, and a great number of those of the second order.

The delicate balancing of the conditions necessary to the accumulation of permanent snow, or *névé* fields, and the formation of glaciers, is well illustrated in the Norwegian mountains. For instance, Sneebræen Folgefon with an area of nearly a hundred square miles is, as already mentioned, a great

* The most trustworthy information in regard to the *névé*-fields and glaciers of Norway is to be found in the publications of the University of Norway, especially those of Kjerulf and S. A. Sexe.

† "Sneebræen Justedal" — the title of this work — is translated by him "Le Névé de Justedal." *Isbræ* is the equivalent of glacier, *en* being the definite article.

centre from which glaciers descend in numbers. The surrounding heights, however, are bare of snow during the summer. The Folgefon *névé* itself lies quite like an isolated mass of snow, and there would, at first sight, seem to be no sufficient reason why the adjacent high land should not be in a similar condition. It appears, however, on closer examination, that the Folgefon plateau is topographically more favorably conditioned for the collection of a continuous mass of snow; and, moreover, it has a little the advantage of the adjacent high land, in that it is better situated to receive the moisture of the prevailing wind, being nearer to the ocean. And yet, to one who had not already had occasion to study the meteorological conditions under which glaciers form and exist in various parts of the world, it could not but seem strange that so large a mass of *névé* as that of Folgefon should maintain itself, in the midst of elevations bare of snow, the situation of which so closely resembles that of the snow-covered region itself.

In the preceding pages all has been said of the present glacial conditions of the great continental mass of Europe and Asia for which space can be found in the present work. The groups of islands north of and not far from the coasts of the region to which our attention has last been turned naturally come next in order for consideration. Since, however, these islands all lie within the Arctic Circle, they properly belong to the North Polar Region, in regard to the general geography of which a few words will be said before proceeding to the details of its glaciation. Iceland, the northern edge of which just touches the Polar Circle, is in the same longitude as part of the eastern coast of Greenland. Its present glaciation may therefore be noticed before taking up that country and the adjacent regions of North America.

That we should have as clear an idea as is possible of the climatic and glacial conditions of both land and water in the higher latitudes is extremely desirable, because the Polar regions are constantly being appealed to as furnishing an illustration of much of that which went on in lower latitudes during the Glacial epoch. Those who find it difficult to understand the nature of the conditions which brought about the glaciation of certain districts in lower latitudes, at a former period, have their attention directed to the Polar regions, as furnishing at the present time an exact parallel to the phenomena which perplex the student of prehistoric glaciation. It is asserted, for instance, with the utmost confidence, that we have only to imagine the climatic conditions of the Polar regions to be repeated in New

England and along the Great Lakes, and we have at once a sufficient cause for all the phenomena of the northern drift and of the surface geology of the region extending from below the line of Pennsylvania northward to beyond the limits of the Continent, and west to the base of the Rocky Mountains. It is true that the Polar regions are difficult of access, and that much remains to be found out in regard to the meteorological and climatic conditions which prevail there; but enough is known, especially of the lands within the Arctic Circle, to materially assist us in the present investigation. It will be found — as the writer believes — on examining the records of the investigations of the most trustworthy explorers of the Polar regions, that the essential points which we have endeavored to bring out in describing the present glaciation of the Alps, the Scandinavian Range, and the Himalaya are repeated on the great land masses north of the Arctic Circle; and that such differences as do present themselves are in harmony with the changed conditions offered by the necessarily peculiar position of those exceptionally situated portions of the earth. But it will not appear from the study of the glacial phenomena of the lands within the Arctic Circle that the facts authorize us to believe that a low temperature is necessarily accompanied by a large amount of snow, and the conversion of that snow into ice; nor shall we find that we may assume — basing our assumption on that which can be seen in the higher latitudes — that a general ice-sheet can form on level land and move in all directions from its centre, or towards a more southern latitude. In short, all the difficulties presented by the glacial and drift phenomena of northeastern North America are *not* removed by a study of the Polar areas.

As preparatory to an examination of the glacial characters of the North Polar regions it will be well to call the reader's attention to the peculiar distribution of land and water in the higher latitudes of the northern hemisphere, a matter which is of the greatest possible importance in connection with the subject before us.

The Arctic Circle lies almost throughout its whole extent on the land, and at the same time it approximately marks the northern limit of the continental land masses. A considerable part of the parallel of 70° does, however, intersect land, because a very small part of Europe and a much larger one of Siberia lie north of that line. Leaving out of consideration the somewhat extensive area between the mouths of the Yenisei and the Lena, which belongs to the continent of Asia, it may be said with truth that, so far as yet discovered, there are no large continuous land masses to the north of the 70th parallel, excepting Greenland. All the rest of the land which exists beyond that limit is made up of islands, usually in groups quite closely clustered together. How much of the area enclosed between the 70th and 80th parallels is land is, as yet, entirely unknown. Any expedition successful in reaching a region previously unexplored may hit upon a group of islands, just as did the Austrians under Weyprecht and Payer. All the land thus far known to lie beyond the 80th parallel is included in the following statement: the extreme northern end of the Spitzbergen group, all of the group known as Franz Josef's Land, and certain areas of unknown extent on each side of the northern passage towards the Pole by way of Smith Sound, of which the land on the east belongs to Greenland, a region not yet sufficiently explored to justify a decision whether it is one coherent mass of land, or whether, to a certain extent, made up — especially in its north-eastern extension — of a group or groups of more or less closely aggregated islands. Nothing is known of the east coast north of the parallel of 77°. Indeed it is not impossible that the lands called by the names of Scoresby and of König Wilhelm, between the parallels of 70° and 76°, may belong to a group of islands having no actual *terra firma* connection with the explored coast of West Greenland.*

Nothing whatever is positively known of the character of the region lying north of the 85th parallel. If destitute of land, it cannot be stated with certainty whether the ocean which occupies that area is entirely frozen: that a large portion of it is can hardly be doubted since the experience of the party belonging to the Nares Expedition and in command of Captain Markham. Previous to that, and especially after Dr. Kane's second voyage, and Morton's report of the open water seen by him from the farthest point he was able to reach, there had been among many Arctic geographers a strong belief in the existence of an open Polar Sea. It now seems quite clearly established that this cannot be the case; and, judging from the character of the frozen surface passed over by Markham's party, it would seem that the chances of ever reaching the Pole over the "palæocrystic ice" are exceedingly small. The general opinion is that although there may be areas of open water among the masses of pack ice in that region, they are not likely to be found sufficiently extensive or continuous to afford any possible hope of navigating a vessel by their means to a much higher

* See farther on, p. 305.

latitude than has yet been reached. That the condition of the ocean near the Pole varies considerably from year to year, in respect to the extent and position of the frozen areas and drift or pack ice, is generally admitted. Whether there has been, on the whole, a gain in the amount of ice within the historic period so as to have rendered navigation more difficult, as suggested in the preceding chapter, is a question which cannot as yet be definitely answered.*

The investigator of glacial phenomena must not forget that the freezing of the ocean and the formation of ice on land are two very different things. If the temperature of the earth were sufficiently reduced there can be no doubt but that the ocean would freeze up, and finally become a solid mass of ice. That this result would be accompanied by a prodigious accumulation of snow or ice on the land, as seems generally to be assumed, can by no means be taken for granted. The evidence collected by explorers of the far northern regions seems to indicate that land in the immediate vicinity of an eternally frozen ocean may itself be but thinly covered with snow. Nor does it appear that the frozen surface of the ocean will have heaped upon it heavy deposits of either ice or snow, so as to form eventually what might be called an ice-sheet of great thickness. The palæocrystic ice-fields do not give birth to icebergs, although the ice-floes detached from them may produce some of those effects often considered by geologists to be exclusively the result of glacier action.

The above general remarks seem all that is necessary as a preliminary to a review of the glacial conditions of the various island groups and land masses of the North Polar region. We may begin with the land nearest to Europe, then take up Greenland and the adjacent parts of North America, and afterwards the less important island of Iceland.

The group of islands known by the collective name of Spitzbergen offers an interesting field for the study of glaciers and the meteorological and topographical conditions influencing their formation. Lying as these islands do in so high a northern latitude (76°–81°) in a position to receive a large amount of precipitation, being in the line of an abnormal warming of the ocean, due to currents coming from southern regions, and being very mountainous, they are necessarily extensively glaciated. But it is not by any means the case that the whole surface of the land is covered with snow or ice; on the contrary, here, as everywhere else, even in this extreme

* See *ante*, p. 240.

northern latitude, the glaciers form on the mountain slopes, and where the topographical conditions are not favorable the rocks are bare during the summer. But on the high table-land of the extreme northern portion, where the elevation is over 2,000 feet, there are large *névé* fields resembling those of the Scandinavian Range, and on an even grander scale. Still, a considerable portion of the lower part of the islands, even beyond the parallel of 80°, is not permanently covered with snow. Indeed the condition of things in Spitzbergen closely resembles that in Greenland, except that its high plateaux are not so thoroughly united into one great snow-field, and their combined area is very much inferior to that attained by the inland ice of that land of almost continental dimensions.

Nova Zembla * also presents an interesting field for the study of glacial phenomena. Lying, as it does, entirely north of the parallel of 70°, and having a quite diversified surface, we find that snow and ice are distributed very unequally over the land. Its mean temperature is, for its latitude, very low. According to Spörer, it is lower than that of Neu Herrnhut, which is situated about half-way up the western coast of Greenland, and lower than that of the northern part of Labrador, or even that of the southern end of Spitzbergen. Spörer gives it as —8°.91 C. The mean of winter is —19°.66; that of summer only 2°.53. Regions where thermometric observations show a considerably lower mean temperature than that of Nova Zembla are inhabited not only by Eskimos, but by Russians, and even English. As Spörer remarks, "the comparatively mild winter, during which mercury very rarely freezes, — and, on the west coast, perhaps not at all — is not sufficient compensation for the cold and foggy summer, which is perhaps the most severe one [der rauheste] known." †

The same sort of condition prevails — as will be shown farther on — in the entirely uninhabited islands in the southern hemisphere, which are situated in a lower latitude than that of some of the most thickly populated regions north of the equator, but where the mean temperature of summer is too low for the human race to exist, although the mean of the year is much higher than that of many regions occupied by thriving communities.

* So called usually in our geographical text-books, but of late years in most books of travel, as well as in the Proceedings of the Royal Geographical Society, spelt more in accordance with the Russian, although by no means uniformly in the same way. The Russian Новая Земля, which means New Land, is perhaps best rendered by Novaya Zemlya, as has been done of late by several geographers writing in English.

† J. Spörer, in Novaja Semlä in geographischer, naturhistorischer, und volkswirthschaftlicher Beziehung, Ergänzungsheft to Petermann's Mittheilungen, No. 21 (1867), p. 63.

In spite of the low mean temperature and the moist climate, the level portions of Nova Zembla are not covered by snow or ice, but are carpeted with grasses and flowers,* and even forests are not wanting, although utterly dwarfed in character, so that they consist of but little else than roots. The importance of this fact makes it worth while to quote, in full, what Spörer has to say on the subject: "Up to this time no one has penetrated to any considerable distance into the interior; but, so far as this has been done, the level land has been found to be destitute of snow. In the interior the temperature must be higher than on the coast. But as no flat region of any considerable extent is known to have a colder summer than this, not even that in the vicinity of the American Pole of cold, Nova Zembla ought, of all known and visited countries, to be the one where the line of eternal snow would descend lowest. It is well known that physicists have dreamed as long and continuously of a land of eternal snow as the non-physicists have of El Dorado, a land of unlimited gold. But both these dreams have, in our world of moderation, remained unrealized."†

The group of islands, of unknown dimensions, lying north of Nova Zembla, and almost entirely beyond the 80th parallel, is also an interesting region for the investigator of glacial phenomena. These islands were discovered in 1873 by the Austrian expedition, of which Weyprecht and Payer were the leaders, and by them named Franz Josef's Land. It is a region of high mountains and large glaciers, of which the exploration was attended with the greatest difficulties and dangers. Nearly all we know of its glacial geology is due to the sledge journey made by Payer between March 27 and May 3, 1874, in command of a party of seven persons. The extent of the group is entirely unknown, but it is believed that some of the islands must be of great size, because they give rise to glaciers of such large dimensions, and of which Payer remarks that their precipitous ends of more than a hundred feet in height form the usual edge of the coast. The most important observed peculiarities of these ice masses were: the small number of crevices, the coarse-grained structure of the ice, the very small amount of morainic material upon them, the entire absence of glacial scratches in their vicinity, their slow motion, and the low elevation to which the line of *névé* descends.

There can be little doubt that the peculiarities exhibited by the glaciers

* Heuglin found 150 species of phanerogams, and about the same number of cryptogams, on the island.

† l. c., p. 64.

of Franz Josef's Land are such as belong to a region of very high latitude where all the conditions are the most favorable to the largest development of ice. But even here the lower land is not entirely covered by the glacial masses, although there are mountains not far distant which reach 5,000 feet in elevation. The following points, however, are of sufficient importance to make it worth while to give in full what Payer has to say in regard to them: "The strong climatic disposition of Franz Josef's Land to the formation of glaciers is shown by the fact that the smaller islands are covered with caps of ice [blasenartig übergletschert], so that a cross-section would exhibit a regular flat segment [of ice], and that many ice streams descending from the high *névé* plateaux spread themselves out over the mountain slopes, and do not as is the case with us [i. e. in the Alps] need to be confined to valleys and basins."* Here also, as in Greenland, the large size of the river channels in the ice showed that immense streams of water poured over its surface in summer, the result of rapid melting under the influence of the sun's rays. Signs of winter thawing, on the other hand, were not perceived, and this naturally connects itself with the absence of apparent motion.

Iceland is in the same latitude and in close proximity to that part of the east coast of Greenland which is most inaccessible, and of which least is known. Its most southern point is in latitude 63°; its northern edge just touches the Arctic Circle. The coast of Greenland opposite and between the same parallels is that desolate region a part of which was explored by Graah and along which the men of the "Hansa" were carried on their ice-floe.† Yet Iceland is somewhat thickly inhabited, has been a highly civilized commercial and intellectual country, with a literature and history of its own of no small value and importance. That the conditions requisite for prosperity and advance are not as favorable as they once were has already been suggested,‡

* Die Oesterreichische-Ungarische Nordpol-Expedition, in den Jahren 1872–1874, Wien, 1877, p. 271.

† See farther on, p. 304.

‡ At a meeting of the Royal Geographical Society held January 30, 1882, after the reading of a paper by Mr. C. E. Peek, the chairman made some remarks, in the course of which he said, that "the inhabitants of the island [Iceland] were perfectly happy," that "they were the most contented race on the face of the earth," and that "they seldom wanted to emigrate," etc. As these statements seem to be in conflict with the idea of a deterioration of the climate of that island, advanced by the present writer, it will perhaps be well to state the fact that the Icelanders have, within the past few years, emigrated extensively, namely to Brazil, Nova Scotia, Ontario, Wisconsin, Nebraska, Alaska, and Manitoba. If a satisfactory climate could be found — that is, one where the Icelander could re-acclimate himself without serious risk of health, — the people would perhaps emigrate *en masse*. At all events, the idea has been under serious consideration, and committees have been sent in search of a "promised land."

and a large amount of testimony could be brought forward in support of that statement. The population is mostly collected on the southeastern end of the island, and agriculture is, to a certain limited extent, remunerative. Portions of the land are, however, quite elevated, and these are covered by snow-fields or *névé*, from which many glaciers descend to a low level,— some nearly to the sea. Much the largest of these is the Vatna Jökull, which has an area of over 3,000 square miles, with an elevation of over 6,000 feet in its highest part. Mr. W. L. Watts crossed this great snow-field, and has published an interesting account of the journey,* but his book gives little information on points important to a student of glacial geology. It appears, however, clear from Mr. Watts's statements that the glaciers of Iceland have been rapidly advancing for some time past. Most of the journey across the Jökull seems to have been made on snow, which had recently fallen to considerable depth.

Greenland, with its exceptional position as being a larger unbroken mass of land than any other in high northern latitudes, presents, as might be expected, peculiarly interesting glacial features. It extends from latitude 60° as far north as exploration has yet reached, or to beyond the parallel of 82°. From 78° north it is separated, on the west, by a narrow channel from what seems to be, if not continuous land, at least a series of islands pretty closely compacted together. Whether this land lying west of Smith Sound, Kane Bay, and Kennedy Channel extends far to the west is quite unknown. This narrow channel opens out a little beyond latitude 82°, and the coast has been found to trend to the west on one hand and to the northeast on the other, indicating the termination of the land masses at this point. From this east and west trending coast line a detachment of the Nares Expedition, in command of Captain A. H. Markham, made its way northward over the frozen surface of the ocean, called by them the "palæocrystic ice," as far as latitude 83° 20′ 26″, this being the most northerly point yet reached by man. From here no indication of land could be seen in the direction of the Pole.

The west coast of Greenland has been traced uninterruptedly from Cape Farewell to the farthest point reached by Lieutenant Beaumont, of the Nares Expedition, in latitude 82° 20′, the coast here trending east, as already remarked. In fact almost all that is definitely known of Greenland is based on observations made on that side, the east coast being much less accessible and therefore only partially explored, and not at all so beyond the parallel

* Across the Vatna Jökull, London, 1876.

of 77°. We may therefore proceed to state what the explorations of the western coast of the country have made known with regard to its glacial condition.

Greenland consists of two quite distinct portions. There is an interior region, supposed, but not proved, to be continuous land, and generally considered to be entirely covered by snow or ice — the so-called "inland ice" or "continental ice." That a large area is thus covered is positively known, because whenever attempts have been made to penetrate into the interior from the west side the country has been found to be thus buried under the snow.* But there is on that side a belt of land of varying width, deeply intersected by fiords, not covered with snow or ice, and comparatively low. This belt is narrow near the southern end of Greenland, but widens out towards the north, and between the parallels of 64° and 74° it has a breadth of from twenty to seventy miles. Rink estimates the area of the continuous portion of the country — that is, of the interior, unbroken, snow-covered mass — at 320,000 square miles; that of the broken, fiord-intersected, mostly ice-free, marginal region, at 192,000 square miles, thus giving a total of 512,000 square miles.

Thus far, all attempts to penetrate sufficiently far into the heart of the country to be able to say positively that it all forms one continuous mass of land, and that the interior is entirely covered by snow and ice, have proved failures, owing perhaps not so much to the physical difficulties which present themselves, as to the fact that the parties who have attempted these explorations have not been sufficiently prepared for the work.† Some authors talk of the possibility of finding, in the interior of Greenland, valleys free from ice, and covered with vegetation, and possibly by forests. The general opinion is, however, decidedly to the effect that the whole higher region is covered with snow and ice. Nordenskjöld gives as one reason why so little is known of the interior, that the natives entertain a superstitious awe of the inland ice, which prejudice communicates itself, in some degree, to Europeans

* The words snow and ice are used somewhat indiscriminately by explorers to describe the covering of frozen precipitation which is spread over so large a part of Greenland. It is really, however, more properly designated as *névé*. It is snow in process of transformation into ice, as will be more fully explained farther on.

† There would seem to be no reason why a party sufficiently large, by establishing depots of provisions in advance and giving themselves to the work as those have done who had no other motive than that of getting somewhat nearer the North Pole than their predecessors, might not find their way across and back. Perhaps this would not succeed at the first trying, because the right place would not necessarily be hit upon at once.

resident in Greenland, and also to those visiting the country for the purpose of investigating it scientifically. This distinguished explorer is, however, not one of those who believe that the whole country is buried under the snow. In discussing this subject he remarks as follows: "There are many reasons for believing that the inland ice merely forms a continuous ice-frame running parallel with the coast, and surrounding a land free from ice, perhaps even in its southern parts woody, which might be of no small importance to the rest of Greenland."*

Everything connected with the condition of the interior of Greenland is of so much interest that it will be desirable to mention the principal attempts which have been made to settle the question of the nature and extent of the inland ice.

In 1751 Dalager started from the bottom of a deep fiord situated just north of Frederikshaab (latitude 62°. 31′), reached the border of the inland ice, and advanced eight miles over it, to some mountain summits projecting above its surface,† since known as "Dalager's Nunatakker," where a reindeer hunt was undertaken. The surface of the ice — for part of the way, at least — was "as smooth as a street in Copenhagen;" portions, however, were excessively rough. The principal obstacle encountered seems to have been defective shoe-leather. Of course the peculiarities of the ice surface at that early time would have excited no attention, and this expedition has no importance except as being the first one in which the surface of the inland ice was actually travelled over.‡ A previous attempt, in 1728, to ride across Greenland on horseback of course proved a failure.

In October, 1860, Dr. Hayes made an excursion into the interior, on the inland ice, as he supposed; as Nordenskjöld thinks, however, not on that, "but on a smaller ice-field connected with it." The point of departure in this case was Port Foulke, which is in a much higher latitude (78°, namely) than that of Dalager's attempt. The surface of the ice must have been comparatively smooth, as he made much more rapid progress than any other

* Redogörelse för en Expedition till Grönland, År 1870. Aftryck ur Öfversigt af K. Vet. — Akad. Förh. 1870. No. 10, p. 21. Also Arctic Manual, p. 390.

† Such a peak or crest projecting above the general level of the inland ice is called a "Nunatak;" plural, "Nunatakker."

‡ There is a brief description of this exploration in Krantz's History of Greenland (quoted in the Arctic Manual, p. 391). The original, in Danish, has not been accessible to the present writer, nor was it to Nordenskjöld himself. (See Geological Magazine, Vol. IX. p. 289.)

explorer has since been able to effect.* The main fact resulting from Dr. Hayes's expedition was, that during the entire journey the surface rose rapidly, so that at the end of it, and at an estimated distance of fifty miles from the edge of the ice, an elevation of 5,000 feet had been attained, and no signs of any change perceived. "We were seventy miles from the coast, in the midst of a vast frozen sahara, immeasurable to the human eye. There was neither hill, mountain, nor gorge anywhere in view."† After reaching a certain point, the elevation of which is not given, "an even plain of compacted snow was reached, through which no true ice could be found after digging down to the depth of three feet."

Professor Nordenskjöld started, in July, 1870, from a point sixty miles south of the ice-fiord at Jakobshavn, or 240 miles north of that of Godthaab, to ascend on to the inland ice, which here comes down to the sea at the bottom of the Auleitsivik Fiord. He reached a point 2,200 feet above the sea-level, and about thirty-three miles from the extremity of the northern arm of the fiord from which they started. The "uncommonly extensive view" which the party enjoyed from a high point of ice ascended at the termination of the route showed that the inland ice continued to rise towards the interior, so that the horizon towards the east, north, and south was terminated by an ice border almost as even as the horizon line of the ocean. Nothing like a moraine was seen, nor were there any scattered boulders on the surface of the ice, except just at its edge. Neither was there anything more than the most inconsiderable amount of detritus occupying the position of a frontal or terminal moraine where the mass of ice terminated. Innumerable streams of running water were met with, and their occurrence often necessitated long detours. The expedition occupied six days, the weather being in every respect favorable. The only obstacle to farther progress seems to have been the difficulty of carrying the necessary food for so long a journey, the two Greenlanders who accompanied them having turned back at the end of the third day.

In May, 1871, Dr. Emil Bessels, who accompanied the American "Polaris" expedition as scientific observer, made an exploration of the inland ice, starting at the same point from which Dr. Hayes, ten years before, had attempted

* The total distance travelled in two days and a small fraction of another was estimated by Dr. Hayes at fifty miles. As no instrumental measurements appear to have been made, it is quite likely that this number is considerably exaggerated, since it took Jensen's party five times as long to travel the same distance.

† The Open Polar Sea, New York, 1867, p. 134.

to penetrate into the interior of the country. The glacier, called by Dr. Kane "My Brother John's," over which the inland ice was reached, was found to be 3,120 feet wide at its termination; and, at a point not far from this, the amount of motion of the ice, near its edge, was ascertained (in May) to have been 8″.6 in thirty hours. Nowhere was any trace of a moraine to be seen in following up the glacier, which rose rapidly and constantly. At a distance of twenty-seven miles from the lower extremity a height of 3,181 feet was attained, and it was here that the line of the *névé* was reached. At this point Bessels, being entirely alone, found himself obliged to turn back. It does not appear that there were any particular obstacles to farther progress connected with the weather or with the surface of the glacier; and it would seem as if, at this point, from which the interior was found both by Hayes and Bessels to be apparently so accessible, a small party, with the necessary assistance for carrying food and covering, might penetrate to a considerably greater distance without much difficulty. It is not stated by Bessels whether the surface of the ice appeared to rise continuously beyond the highest point reached by him; but it is mentioned that from a point eight miles above the termination of the glacier the eastern horizon was nothing but a line of snow, above which not a single peak rose.

The next attempt to explore the interior of Greenland, from the west coast, was made by Amund Helland, and it was more systematic than any which had been previously undertaken. This observer spent the months of June, July, and August, 1875, in examining the region between the colony of Egedesminde (latitude 68° 42′) and the fiord Kangerdlugssuak (71° 15′). The southern limit of Helland's field of exploration was in the immediate vicinity of the point from which Nordenskjöld started, as mentioned above (68° 20′). Helland ascended upon the inland ice in several places, measured the dimensions of some of the glaciers by which, along that part of the coast, its overflow is carried down to lower regions, and determined their rate of motion at several points, and especially that of the great glacier at the head of the Jakobshavn Fiord. He did not succeed, however, in penetrating into the interior to any considerable distance, although there seems to have been no special difficulty in the way of doing this connected either with the weather or the character of the ice surface. Helland describes the inland ice, in most respects, very much as Nordenskjöld does, noting especially the absence of detritus on its surface and the large number of running streams, the season of the year being midsummer. He considers it an established fact that the ice is continuous — on the west side, at least — from one end of Greenland to the other, although its edge is at a considerable distance from the coast (sixty or seventy miles) between the parallels of 65° and 70°.

The measurements made by Helland of the rate of motion of various parts of the Jakobshavn glacier are interesting. At a point about a thousand meters from its edge the velocity of the ice was found to be at the rate of nearly twenty meters in the twenty-four hours. The difference between the rate of motion of the ice near the edge of the mass and farther towards the centre was very great. In one case the very edge of the ice moved only 0.02 meter in twenty-four hours.

The very great rapidity of motion cited above is the more remarkable, since the surface of the ice at that point was quite free from crevices, and its angle of slope only about half a degree. These observations, it must be remembered, were made in midsummer, at a time when the temperature of the air in the shade was about 10° (C.). What the rate of motion in the winter may be is entirely unknown; that it is very small seems indicated by such observations as have been made in the spring. That there is some motion seems clearly proved, according to Helland, since the formation of icebergs does not entirely cease at that season.

All observers agree in this: that, when the glaciers or arms of the inland-ice have been followed for some distance, the mass of ice or snow becomes continuous, all or nearly all the highest peaks being concealed under it. Helland's observations, however, are in one important respect different from those of any other explorer. From the highest point of the inland ice reached by him, he looked *down* upon the farther extension of the mass to the east: in other words, the ice covering of the land was higher near the sea than it was farther inland. This observation is of such importance — so it appears, at least, to the writer — that an exact translation will be given of the passage in which this statement is made: "The five places in which I have had an opportunity to overlook this ice wilderness presented, in all respects, the same appearance. It is, on the whole, like looking out over the ocean. It appears to raise itself, and stretch out with waving lines towards the horizon. Remarkable is it that this undulating surface seen in the distance lies lower than that nearer the observer, so that from the point of observation one looks down and not up on to the ice-fields. Most remarkable is this in the case of the fiord at Kangerdlugssuak, where the glaciers in front of the ice-field seem, so far as can be judged by the eye, to be several thousand feet higher than the inland ice below."*

In 1876 the Danish government authorized a systematic scientific exploration of the west coast of Greenland, which was to be continued during a period of at least five years, and which, although not on a large scale, has yielded results of great interest.† The amount and character of the work done, so far as known to the writer, may be indicated by the following *résumé*. In 1876 K. J. V. Steenstrup explored a portion of the district of Julianshaab, devoting himself chiefly to its geology. The next year, the same observer, with the assistance of Lieutenant Jensen, examined the region near Frederikshaab, mapping the interior ramifications of the fiords, and the borders of the inland ice. This year, however, they were prevented by continuous bad weather from making the desired explorations of the interior ice and snow-covered region.

In 1878 Steenstrup started for more northern and unknown regions, in the vicinity of the Umanak Fiord and on the peninsula of Svartenhuk (between the parallels of 71° and 72°). His return to Copenhagen was expected in November of 1881. In 1879 he explored the Torsukatak glacier (latitude 70°); and in 1880, with the assistance of Hammer, he continued his work in the vicinity of the Umanak Fiord. The results of these investigations do not appear to have been yet made public.

Jensen, in 1878, explored the portion of the coast of Greenland lying between the fiord of Ameralik, in the district of Godthaab and Tiningnerlok, a little south of the Isblink of Frederikshaab, a region embraced within the parallels of 62° 15′ and 64° 30′, and he succeeded, with the assistance of Messrs. Kornerup and Groth, in making a more detailed and satisfactory examination of a portion of the inland ice than any one of his predecessors in this line of exploration. His results are especially valuable, because he was furnished with instruments, so that his distances and elevations could be determined with considerable approach to accuracy.‡ This party ascended the Isblink of Frederikshaab, a great arm of the inland ice coming down

* A. Helland, Om de isfyldte Fjorde og glaciale Dannelser in Nordgrønland (Separataftryk af Archiv for Mathematik og Naturvidenskab, Bind I.). Kristiania, 1876, page 7.

† See Meddelelser om Grønland, udgivne af Commissionen for Ledelsen af de geologiske og geographiske Undersøgelser i Grønland. Hefte 1, 1879; 2, 1881; 3, 1880; the last-named is devoted to the botany of the region.

‡ This party was ten days in making about the same distance on the inland ice which Dr. Hayes thought he had made in a little over two. This would seem to indicate that the character of the surface was very different in the two localities, or else that the distance travelled by the latter was considerably overestimated.

nearly to the sea-level, taking at first nearly the same route as that followed by Dalager. They, however, penetrated much farther than he did, reaching in ten days a group of nunatakker, called after the leader of the expedition, at a distance of about fifty miles from the coast. Here camp was made at an elevation of 4,030 feet, and at the foot of a nunatak, the summit of which was 4,960 feet above the sea-level. After being obliged to remain in camp during a violent snow-storm lasting seven days, they were able to ascend an adjacent peak, from which they had an outlook on to the ice, which extended for an indefinite distance eastward, and rose gradually, its surface being unbroken by any other projecting summits in that direction.*

Having thus given a sketch of the principal results of the scientific expeditions sent out to explore the inland ice of Greenland from its west side, it will now be proper to give a brief statement of what is known of the topographical and glacial conditions on the eastern border of that country.

It has already been mentioned that, owing to a misunderstanding as to the position of the lost colony called the Eastern Settlement (Österbygd), and hence supposed to be to the east of Cape Farewell, numerous exploring expeditions were despatched to that side of Greenland, all of which were unsuccessful.† In reality the east coast is much less accessible and by no means so well known as the western.‡ The latter is inhabited at intervals up to the parallel 78°; on the eastern side it is not known that there are, or have been in recent years, any inhabitants beyond latitude 65°.§

* Jensen's Nunatakker were seen by Dalager, and by him supposed to be on the east coast of Greenland.

† See *ante*, p. 239.

‡ Hudson, in 1607, sighted the land on the east coast of Greenland, named it "Hold with Hope," and found its latitude to be 73°. In 1654, a Dutch captain, named Gale Hamke, also saw land, and a bay was marked with his name on the old Dutch charts. It still has its place on our maps, and is put in latitude 74° by the Second North German Expedition. Another Dutch chart shows land forming part of the east coast, in latitude 77° 10′, and called "Land van Edam." This was discovered in 1655. Still farther north, in latitude 78° 20′, another part of the coast was sighted in 1670, and marked on the chart as "Land van Lambert." Between this and the farthest point reached by Lieutenant Beaumont of the Nares Expedition, in latitude 82° 19′ and longitude 51°, there is no definite information with regard to Greenland. From this point land was visible in the distance trending to the northeast; but whether the various headlands seen belonged to a group of islands, or to Greenland proper, could not be made out.

§ In 1861, according to Rink, there were supposed to be from 800 to 1000 inhabitants on the east coast, between Cape Farewell and Angmagsalik, the most northern known settlement, believed to be a little north of the parallel of 65°. It is thought that this place is not far to the north of the northernmost point reached by Graah on his exploring expedition (1828–31). There are strong reasons for believing that this coast may now be entirely depopulated. At all events, no inhabitants have been met with since the time of Clavering and Sabine's Expedition.

Of the many expeditions sent to explore the east coast only the following have had much success or brought back any information beyond the simple fact of the existence of land. Scoresby, in 1822, forced his way through the ice and surveyed the coast line from Gale Hamke's Bay, in latitude 74°, down to latitude 69°. He found the coast to be bordered by lofty mountains which rose precipitously from the shore to the height of 3,000 feet and more. The coast line was deeply indented, so that he thought the land probably consisted of an assemblage of islands. Large glaciers coming down from the mountains sent off icebergs, and these helped to swell the belt of ice which stretched along the coast with a width of a hundred miles.

Clavering and Sabine, in 1823, in the course of their pendulum expedition to the north, laid down a stretch of coast between the parallels of 72° and 76°. The same accounts of lofty precipitous shores, deeply indented by bays and fiords, were brought back by these explorers. They also reported having met with natives in the Bay of Gale Hamke.

Graah, in 1828 – 31, made an adventurous exploration of the coast, in native boats, from Cape Farewell north, penetrating with great difficulty as far as latitude 65° 15′. Previous to the Second North German Expedition, in 1869 – 70, nothing was known of East Greenland, beyond the fact that it is bordered by lofty and precipitous mountains, from which great glaciers descend, and that the coast line is so broken as to leave it uncertain whether it is a group of islands, or a single mass of land deeply indented with immense fiords. This information applied, however, only to the line of coast between the parallels of 70° and 75°, visited by Scoresby and Clavering. North of 75°, and between Graah's farthest northern point (65°) and Scoresby's most southern (70°), the map was a blank, and indeed it remains nearly so to this day.

The officers and crew of the crushed ship "Hansa," of the Second North German Expedition, were carried near it in their drift south, while camped on an ice-floe, and they were able to fix the position of a few points. In latitude 67° they were within two miles of the coast, which is described as precipitous, and having here and there small glaciers at the bottoms of the bays, with high snow-covered mountains in the background. The scientific corps of the second ship of the same expedition, the "Germania," among whom was Payer, a skilful Alpine explorer, made important additions to our knowledge of the coast between the parallels of 73° and 77°. The published results of this expedition show that the glacial and topographical conditions on the east side of Greenland, while in some respects similar to those on the western coast, are in other important ones quite different. Except at the extreme southern end of Greenland, there seems to be nothing on the east side which is exactly like the inland ice as described in the preceding pages. Indeed Payer gives strong reasons for believing that the land examined by his party consists of an aggregate of islands, and that it is not a part of a continental mass intersected by deep fiords. At all events, they followed up one of these indentations for a distance of four degrees of longitude, and then ascended a mountain 7,000 feet high, from which they could command a view over one-third the width of Greenland in that parallel; from this point, however, no signs of the closing up of the straits or fiord could be discerned.

The whole aspect of the land in the region explored by Payer is much more Alpine than it is on the western side. The mountains are more broken and irregular, and—in places, at least—much higher, Petermann Peak, in latitude 73°, being estimated at 13,000 feet in elevation. The glaciers are subordinated in position to the high peaks, and have their moraines, both lateral and terminal, like those of the Alpine ranges, and on a still grander scale. In short, the conditions do not help us much in coming to any definite opinion as to the extent of the inland ice on the other side.

There are portions of the country on the east side of Greenland where the small amount of snow has made a strong impression on explorers. Captain Koldewey, the chief of the Second North German Expedition, says, in speaking of the character of the ice on the mainland opposite Shannon Island (latitude 75°): "We ascended the steep although not very elevated Cape Wynn, and found there a plateau of several miles in circumference, which was entirely clear of snow, although only sparsely covered with vegetation. Farther inland we reached a valley through which runs a brook fed by a glacier, and which shows many green places covered with moss and grass. Behind this valley were mountains rising to a height of over 600 meters; but their summits were free from snow, which had collected in the ravines only. The snow covering, and the precipitation generally, in Eastern Greenland, are far less than would have been expected, certainly less than on the opposite shores of Spitzbergen. During our whole stay on this coast we only once saw the whole country covered with snow; that was in June, 1870." *

* Zweite Deutsche Nordpolarfahrt, Vol. I. p. 318.

As far as observed, the east coast of Greenland resembles a range of Alpine mountains; except, of course, that the glaciers descend in places nearly to the sea-level. There is evidently less precipitation on the eastern side than on the western; this circumstance, taken in connection with the greater elevation and much more broken character of the ranges on the east coast, would seem to be sufficient to account for the marked differences in the development of the ice on the two sides of the continental mass of land.

Between the more or less imperfectly known edges of Greenland there is a region from 200 to 400 miles in width, measured on an east and west line, in regard to the condition of which we know nothing with certainty.

After studying with care all that has been published by the different Arctic explorers, and allowing special weight to the opinions of those persons whose previous training had prepared them to form a correct idea of the glacial phenomena of Greenland as compared with those of other regions, the writer is of opinion that the inland ice is a feature peculiar to the southern extremity and western coast of that country, and that the interior is not necessarily heavily covered with snow or glacial accumulations. It is admitted, however, that, since we know nothing definite of the topography of that interior, we are hardly justified in expressing an opinion in regard to the extent of its glaciation. If we knew that the land rose gradually from the coast towards the centre of the country to a great elevation, and then declined to the sea-level on the other side, it would still be no easy matter to say how deeply that highest central ridge would be covered with snow. The occurrence of high mountain ranges on both sides of Greenland seems decidedly to militate against the idea of still higher ones in the unknown central portion. If the edges of any land mass of great width are raised to a considerable elevation, the area between them is likely to be depressed — that is, in comparison with the edges themselves — so as to form a high plateau, or a series of plateaux, with minor ranges between. That this orographically probable lower central portion of Greenland is a region of attractive climatic features, and considerable agricultural capacity, as supposed by some, seems hardly probable, although not absolutely impossible. That it may be only thinly covered with snow is a reasonable supposition, since much of the precipitation might be cut off by the higher edges of the land mass. If the statements of Helland — who seems a most conscientious observer — may be accepted as correct, portions of the inland ice, not far from its western border, are considerably depressed below other areas lying nearer the coast. This fact does not favor the idea of one great central depression occupying all the interior of Greenland, filled to the brim with snow and only discharging by actual flow from a higher to a lower level through the gaps in the surrounding frame-work of mountains. But as no other observer has reported anything else than a gradual rise of the land, on the west coast, from its lower edge eastward so far as followed, it will perhaps be well not to indulge in speculations on the extraordinary conditions described by Helland.

We have thus become acquainted with the principal sources of information in regard to the glacial geology of Greenland. Some of the more important facts developed in the course of the different explorations have been already stated; others will come up for consideration and discussion farther on in their proper connection, or where they may seem likely to throw light on difficulties presented by facts pertaining to a period of greater previous extension of ice over certain regions. At the present stage of our discussion the most important question to be considered is, whether throughout the various land masses of the northern circumpolar region similar conditions are exhibited in regard to glaciation; or, in other words, is there a continuous ice-cap, or anything resembling one, over the farthest northern lands. We have already seen that for Greenland itself this is not the case. There is on the west side a broad strip upon which the inland ice does not encroach. In fact where the mountains recede from the coast, there the ice does the same; it is only where the topographical conditions are favorable that the glacier descending from the interior finds its way to the sea. On the east side, as we have seen, the freedom of certain regions from ice and snow is indeed remarkable. A similar condition of things is revealed when we come to examine the other lands not previously included in our review of the Polar regions.

Most interesting in this respect is the contrast in the condition of things on the two opposite and closely adjacent sides of Kennedy Channel. De Rance and Feilden say "The absence of an ice-cap in Grinnell Land, and the paucity of the glaciers in that region, are worthy of note, none descending to the sea-level north of 81°; while on the same parallel on the opposite coast of Hall Basin, on the Greenland coast, the country is ice-clad to the water's edge."* Captain Nares also remarks: "We cannot definitely state that we

* Voyage to the Polar Sea, Vol. II. p. 343.

met with glaciers in Grinnell Land, between the 82d and 83d parallels."* Dr. Hayes says of the same region: "Along the entire coast of Grinnell Land no glacier appears. The land behind was elevated, and lofty peaks were seen, on which snow rested, but nowhere was there any evidence of mountain ice."† Bessels remarks as follows in regard to the glaciation of the coast opposite the west side of Greenland: "It is a noteworthy circumstance that the larger portion of the continental mass of Greenland lies buried under ice [unter Eismassen begraben], while on the west side of the channel, north of the 79th parallel, so far as known, there are no glaciers. Hayes Sound, which separates Ellesmere Land from Grinnell Land, forms along its southern boundary the line of demarcation between two regions, one of which is at present in the condition of the Glacial epoch [in der Periode der Eiszeit], while the other, for reasons which still await explanation, has already laid aside its icy yoke."‡

On the lofty United States Range, to the northwest of Archer Fiord, beyond the parallel of 81°, the glaciers appear to be few in number, and to terminate at a considerable height above the sea-level. Even the "Victoria and Albert Range," lying between the parallels of 80° and 81°, and estimated to be 5,000 feet in elevation, "does not send down a single glacier to a point nearer than ten miles from the sea."§

The same is true in regard to the comparatively level land of the great cluster of islands north of that part of North America which extends between Hudson's Bay and the mouth of the Mackenzie River. Of this region Sir J. Richardson remarks as follows: "There are no ice-bergs of any size in the Arctic American sea, from the absence of glaciers to furnish them, either on the continental shore, or islands due north of it."||

The same author, in his "Journal of a Boat Voyage through Rupert's Land and the Arctic Sea," says: "Nowhere on the route of the Expedition is the snow permanent; not even on the summits of that part of the Rocky Mountains which skirts the Mackenzie. . . . . In favourable seasons, at Melville Island, in lat. 74¾° N. and long. 110° W., the snow toward the end of June lies only in the valleys where it had drifted deeply, and the level meadows remain uncovered for seventy days, or till the beginning of Sep-

* l. c., Vol. I. p. 324.

† The Open Polar Sea, p. 341.

‡ Die Amerikanische Nordpol-Expedition, p. 122.

§ Nares, Voyage, etc., Vol. I. p. 333.

|| The Polar Regions, p. 239.

tember. . . . . When the rigour of the climate of Arctic America is considered, the under limit of permanent snow on the hills appears to be very elevated." *

To the same effect is the testimony of Sir Edward Belcher in regard to the glacial condition of the land about Northumberland Sound, his winter-quarters in 1852–53. He says: "No bergs are to be seen in these seas. . . . . Vegetation in the great belt of this island [Exmouth Island, lat. 77°. 15′] appeared to be more luxuriant than we have elsewhere witnessed in this region. . . . . These are *not* invariably, even in winter, 'snow-clad' regions. Grave Mountain, 1,400 feet high, in latitude 76° 23′, had no snow on it in May, 1853. The hills are never 'snow-clad'; the fall of a few days is dispersed in a few hours, and the last gale preceding actual winter puts an end to heavy falls of snow, by reason of extraordinarily low temperatures." †

As there are no glaciers and no permanent snow on the northern coast of America, or on the islands adjacent, so there are none in the corresponding parts of Asia. The whole coast of Siberia, of which the Taimyr Peninsula reaches at its most northern point nearly the latitude of the southern edge of Spitzbergen, is also destitute of glaciers. Middendorff says that he reached, in Taimyr Land, the latitude of 75½°, and found there unexpectedly a region of continuous mountains which although a thousand feet in elevation were not covered with snow.‡ This condition of things on the Siberian coast is corroborated by Nordenskjöld, who says, in writing of the low part of Nova Zembla: "There are no true glaciers here, nor any erratic blocks, to show that circumstances were different in former times. . . . . It is therefore possible at a certain season of the year (during the whole of the month of August) to sail from Norway to Novaya Zemlya, make sporting excursions there, and return without having seen a trace of ice or snow."§ Farther on, he remarks when speaking of the group of the New Siberian islands: "All was now clear of snow [the month was August or September] with the exception of a few of the deeper clefts between the mountains. No traces of glaciers were visible, not even such small collections of ice as are to be found everywhere on Spitzbergen where the land rises a few hundred feet above the surface of the sea. Nor, to judge by the appearance of the hills, have

* l. c., Vol. II. pp. 212–215.

† The above are quotations from the "Last of the Arctic Voyages," 2 vols., London, 1855.

‡ Quoted by Payer, in Die Oesterreichische-Ungarische Nordpol-Expedition, Wien, 1877, p. 563.

§ The Voyage of the Vega around Asia and Europe, English edition, London, 1881, Vol. I. p. 73.

there been any glaciers in former times, and this is certainly the case on the mainland. The northernmost part of Asia has therefore never been covered by such an ice-sheet as is assumed by the supporters of a general ice age embracing the whole globe."*

The facts, as set forth in the preceding pages, show clearly that ice and snow are very differently distributed in different portions of the Northern Polar regions. And it will require but little examination to convince the inquirer that where the amount of precipitation is small — no matter how high the latitude, or how low the mean temperature — there glaciers will not be formed, and snow will not lie during the whole year. It is only when the winter snow-fall is so abundant that the summer sun cannot melt it all away, that the ground remains permanently covered. It is also evident that snow may remain permanently, and yet not be converted into ice, as shown in the case of the farthest northern land on the west side of Kennedy Channel.

Examination of the climatic conditions prevailing in that part of the globe where there exists the most thorough glaciation will show at once that the lands thus covered by ice and snow are exceptionally situated with reference to prevailing winds and ocean currents, so that they unite all the requisites for the accumulation of snow in large quantity, its descent into regions where during the Polar summer it becomes converted into ice, and finally in the form of icebergs is carried to more southerly latitudes to be converted back to water, and thus be ready to be taken up as moisture, and again to fall as snow on the mountains of Greenland and the groups of islands lying farther to the northeast.

Before proceeding to a brief discussion of the facts laid before the reader in the present section, it will be proper to examine the climatic and glacial conditions prevailing in the Southern Polar regions, to see if any additional light can be thrown on the problems before us from that quarter of the globe.

Our knowledge of the North Polar lands and seas — unsatisfactory as it may seem to be — is still very complete, as compared with the little which has been definitely found out in regard to the regions at the opposite Pole. Indeed, a few pages will suffice to tell all that we know of those lands on which the foot of the scientific explorer has never trod for more than a few

* l. c., Vol. I. p. 418; German edition, Vol. I. p. 379. The above quotation has been corrected from the English translation, which is full of errors.

hours at a time.* And yet the condition of things at the South Pole is being constantly appealed to, as rendering the phenomena of the "Glacial epoch" perfectly easy of comprehension. This is perhaps not so erroneous as that which is commonly done by writers on glacial questions, when illustrating their theories by reference to the continental ice of the North Polar regions; because, in this latter case, well ascertained facts are — as a general rule — positively ignored, as must have become evident from what has been set forth in the preceding pages; while, in regard to the opposite hemisphere, advantage is merely taken of our almost entire ignorance of what really exists there to make positive statements, and to assume that precisely that condition of things which it is theoretically most desirable to have at the South Pole really does prevail in that region.

In point of fact, we do not know — even approximately — how much land there is in the southern hemisphere, nor what the topography of that land is, nor how much of it is covered with snow or ice. As already remarked, a few lines will give all the positive information we have on these points, which are those of importance to us, from the point of view of our present inquiry.

It is, of course, in reference to what lies within the Antarctic Circle that this statement is made. That there is extremely little land in the southern hemisphere, as compared with the northern, is a well-known fact, as also that there is almost no land at all between the 40th parallel and the Antarctic Circle. The contrast between this condition and that at the opposite pole is most striking; in the northern hemisphere there is an almost continuous mass of land around the globe in the very region where in the southern all is water.

There are some islands in low southern latitudes north of the Antarctic Circle, and the difference between their climatic condition and that of the land in corresponding latitudes north of the equator is indeed most remarkable. High latitude and extremely low mean temperature do not seem to render the northern hemisphere uninhabitable, for there is hardly any land there entirely unoccupied by man, the Esquimaux ranging as high as 78°. On the opposite of the equator the inhabited land having the highest lati-

* The Wilkes Expedition never set foot on the land during their Antarctic discovery cruise. Sir J. C. Ross landed — for a few hours, apparently — on Franklin Island, in latitude 76° 8′, and on Possession Island, latitude 71° 56′, both off the coast of Victoria Land; no other landings were made by this party. The French expedition, under D'Urville, also made one landing on a small island close to Adelie Land, and remained there for a part of a day.

tude is Tierra del Fuego, in about 55°. There is a small settlement on Falkland Island, a little south of 50°. St. Paul's and Tristan d'Acunha have also some inhabitants, their position being in 37° and 38° — about the same distance south of the equator as the Azores are north. The difference in the character of the climates of these islands in corresponding positions north and south of the equator is indeed remarkable.* Kerguelen Island, in about the same latitude as Prussia, and half as large as that country, has no inhabitants. The mean temperature on the Falkland Islands of the warmest month is 55° (F.), and of the coldest, 37°.5. The mean of the year is 47°. This shows, as contrasted with the low mean temperature of portions of the inhabited parts of Europe, Asia, and the North Polar region, that high mean temperature is less important than is ordinarily supposed, and that a very cold winter may be tolerable if the summer is warm. In short, an even climate, within certain limits, is less desirable than one of great extremes.

The amount of land in the South Polar region is estimated by Behm and Wagner at 250,000 square miles,† which is not quite one-third the area of Greenland, as given by the same authorities. But nothing can be more uncertain than this estimate of the land surface in a part of the world of which so little is known, for the unexplored region at the South Pole embraces an extent of over 8,000,000 square miles. This was formerly considered as being chiefly, or largely, land, and called the "Antarctic Continent"; but Petermann ‡ has shown how little foundation there is for this

* It seems somewhat doubtful whether the small settlement on Tristan (with a population, in 1867, numbering eighty-six souls) can be continued after the scanty supply of firewood has been exhausted. See Voyage of the Challenger. The Atlantic. London, 1877, Vol. II. pp. 157–176.

† This estimate includes several small groups of islands north of the Antarctic Circle — namely, South Georgia, and the South Orkney and South Shetland Islands. The land discovered by Ross (Victoria Land) is put down at 127,000 square miles; "Wilkes Land" at half that, its average breadth being assumed as fifty miles. The so-called "Wilkes Land" — a name not usually recognized on English maps — consists of a chain of headlands stretching in close proximity to the Arctic Circle, between the meridians of 95° and 160° E. longitude, and supposed by the Chief of the United States Exploring Expedition (1838 – 42) to form a continuous continental mass. Captain Wilkes did not, however, land at any point, or approach the coast near enough to fix its exact position, and in fact a considerable portion of the newly discovered continent was afterwards sailed over by Ross, who found several hundred fathoms of water on it. It is doubtful if Wilkes's discoveries would now be accepted as genuine, had not land been positively ascertained to exist at various points along the line of his reported continent both before and since his expedition. Wilkes Land was first seen by Balleny, in 1839; and this navigator left no doubt of the truthfulness of his assertion of its existence, since he landed and also saw volcanoes in eruption. The French expedition, under D'Urville, also discovered land (called by him Terre Adélie) in the vacant space between two points laid down by Balleny — Claire Land and Balleny Islands. These all form a part of the coast line of Wilkes Land. The name of Balleny is not mentioned in Wilkes's narrative of his explorations.

‡ See an article entitled "Neue Karte der Süd-Polar Regionen," in Petermann's Mittheilungen, 1863, p. 410.

idea, and how, as each discovery of land in South Polar waters has been more thoroughly examined, continental masses have resolved themselves into small groups of islands. That eminent geographer remarks as follows, at the close of a discussion of this question: "It is very probable that the Antarctic Zone may have only comparatively small islands to show in the way of land; and that the coasts which have thus far been discovered may shrink up [zusammenschrumpfen] into islands, when they come to be more closely examined. . . . . So too the experienced navigator Sir James C. Ross is of opinion that the coast seen by Balleny, D'Urville, and Wilkes (Wilkes Land) is only a chain of islands. Certain it is, that all those portions of the Antarctic lands which have been closely examined, and fully laid down on the map, have turned out to be islands, and comparatively small ones, like the South Orkney and the South Shetland groups."*

It has been generally thought that the quantity of pack ice and icebergs observed in the ocean south of the equator indicated the existence of a great continent from which these floating masses must have come. Petermann has made a careful examination of the distribution of the drift ice in the southern seas with the following results.† 1. The most northern boundary of the Antarctic drift ice forms an irregular curved line, extending between the parallels of 33° and 58° S. latitude. 2. The ice makes its way farthest to the north in the neighborhood of the Cape of Good Hope; and keeps most to the south in the region of Cape Horn. 3. On the average, the most drift ice is found in the Atlantic Ocean, and the least in the Pacific and in the seas south of Australia and New Zealand; so that, in this respect also, the "Great Britain of the Southern Ocean" is most highly favored. 4. The Antarctic drift ice is met with chiefly in the southern summer months (December — February); it is rarely, if ever, [am wenigsten, ja fast gar nicht] encountered in the winter (June — August). From the latter circumstance he concludes that the ice forms chiefly along the coast, by freezing of the ocean, which ice is detached by the melting power of the summer sun and floats north, driven by winds and currents.

That much, if not most, of the Antarctic drift ice is formed by freezing of the ocean, and is not the ice which is born of glaciers in the form of bergs, seems evident from the descriptions and illustrations given by the

* l. c., p. 416.

† l. c., p. 416, under the head of "Die Verbreitung und Ausdehnung des Treibeises." This term *Treibeis* of course includes both pack ice and icebergs.

different Antarctic explorers. It is quite remarkable that the largest amount of drift ice comes from that quarter where the Pole has been most nearly approached without finding any signs of land; * while, on the other hand, the ocean least encumbered by bergs and floes is that which lies north of and in nearest proximity to the largest known mass of Antarctic land.†

Nearly all that is known of the glaciation of any part of the South Polar land is derived from Sir J. C. Ross's narrative of his voyage along the shore of Victoria Land and to the east for a short distance. The line of coast explored by this eminent navigator extends between the parallels of 70° and 78°, with a general north and south trend, and it rises precipitously in lofty mountains, which appear to form one continuous range, although distinguished by three names — the Admiralty Range, the Prince Albert Mountains, and the Parry Mountains. Of the first-named of these Captain Ross says: "We had a most enchanting view of the two ranges of mountains, whose lofty peaks, perfectly covered with eternal snow, rose to elevations varying from seven to ten thousand feet above the level of the ocean. The glaciers that filled their intervening valleys, and which descended from near the mountain summits, projected in many places several miles into the sea, and terminated in lofty perpendicular cliffs. In a few places the rocks broke through their icy covering, by which alone we could be assured that land formed the nucleus of this, to appearance, enormous iceberg."‡

In farther illustration of the glacial and topographical features of Victoria Land the following quotations may be made.

"At noon [January 15, 1841] we were in lat. 71° 56′ S., Possession Island bearing true west of us distant seven or eight miles. . . . . Whilst measuring some angles for the survey, an island I had not before noticed appeared, which I was quite sure was not to be seen two or three hours previously. It was above one hundred feet high, and nearly the whole of the summit and eastern side perfectly free from snow. I was much surprised at the circumstance, and on calling the attention of some of the officers to it, one of them

* Weddell sailed south to latitude 74° 15′, in longitude 34° 16′ W., or more than thirty degrees south of the northern limit of drift ice in this part of the ocean, and found an open sea and pleasant weather, a mild wind blowing from the south. Not being engaged in scientific exploration, he found himself unable to follow up the chance thus offered for penetrating far to the south.

† Wilkes Land and Victoria Land, which may, very possibly, be united into one mass.

‡ A Voyage of Discovery and Research in the Southern and Antarctic Regions, during the Years 1839–1843. By Captain Sir James Clark Ross, R. N. 2 vols. London, 1847. Vol. I. p. 185.

remarked that a large berg which had been an object of observation before, had disappeared, or rather had turned over unperceived by us, and presented a new surface, covered with earth and stones, so exactly like an island that nothing but landing on it could have convinced us to the contrary had not its appearance been so satisfactorily explained; and, moreover, on more careful observation a slight rolling motion was still perceptible. . . . . I was very desirous to find a harbor in which to secure the ships, ... and for this purpose I had examined every indentation of the coast that presented itself. These were, however, all filled with drifted snow from the mountains, and formed a mass of ice several hundred feet thick; and thus we found it impossible to enter any of the valleys or breaks in the coasts where harbours in other lands usually occur." *

"The form of Mount Melbourne [latitude 74° 15′] had so general and striking a resemblance to Mount Ætna, that for distinction's sake it went by that name for several days amongst the officers of both ships; but its elevation must be very much greater than that of the Sicilian mountain. The land ice, although not more than five or six feet above the surface, and therefore probably not more than forty feet in thickness, blends so imperceptibly with the snow which descends from the mountains at this part and extends far into the sea, that it was almost impossible to form any idea of the exact position of the coast line; thus from the edge of the land ice, it seemed at no great distance from its margin gradually to ascend until it reached the summits of the highest mountains." †

"As we approached the land [just north of two active volcanoes named Terror, 10,900 feet in height, and Erebus, 12,400 feet] we perceived a low white line extending from its extreme eastern point as far as the eye could discern to the eastward. It presented an extraordinary appearance, gradually increasing in height as we got nearer to it, and proving at length to be a perpendicular cliff of ice, between 150 and 200 feet above the level of the sea, perfectly flat and level at the top, and without any fissures or promontories on its even seaward face. What was beyond it we could not imagine; for being much higher than our mast-head, we could not see anything except the summit of a lofty range of mountains extending to the southward as far as the seventy-ninth degree of latitude. These mountains, being the southernmost land hitherto discovered, I felt great satisfaction in naming

* l. c., Vol. I. pp. 195, 196.

† l. c., Vol. I. pp. 205, 206.

after Sir Edward Parry. . . . . Whether 'Parry Mountains' again take an easterly trending, and form the base to which this extraordinary mass of ice is attached, must be left for future navigators to determine. If there be land to the southward, it must be very remote, or of much less elevation than any other part of the coast we have seen, or it would have appeared above the barrier."*

This ice cliff or barrier was followed by Captain Ross as far as 198° W. longitude, and found to preserve very much the same character during the whole of that distance. On the lithographic view of this great ice sheet given in Ross's work it is described as "Part of the South Polar Barrier, to 180 feet above the sea-level, 1,000 feet thick and 450 miles in length."

A similar vertical wall of ice was seen by D'Urville, off the coast of Adelie Land. He thus describes it: "Its appearance was astonishing. We perceived a cliff having a uniform elevation of from 100 to 150 feet, forming a long line extending off to the west. . . . . Thus for more than twelve hours we had followed this wall of ice, and found its sides everywhere perfectly vertical and its summit horizontal. Not the smallest irregularity, not the most inconsiderable elevation, broke its uniformity, for the twenty leagues of distance which we followed it during the day, although we passed it occasionally at a distance of only two or three miles, so that we could make out with ease its smallest irregularities. Some large pieces of ice were lying along the side of this frozen coast; but, on the whole, there was open sea in the offing [au large]."†

There can be no doubt that these ice barriers described by Ross and D'Urville are extremely interesting, since they have far more the aspect of a "Polar ice-cap" than anything observed in the Arctic seas. At all events they have been frequently described as such by writers on the Glacial epoch, and freely used to explain and illustrate the condition of things during the "Great Ice-Age." It will be desirable, therefore, to introduce at this point a few words as to the nature and probable origin of these extraordinary ice masses.

First, however, the peculiar climatic conditions of the Antarctic Polar

* l. c., Vol.I. pp. 217–219.

† Voyage au Pole Sud et dans l'Océanie sur les Corvettes l'Astrolabe et la Zélée, exécuté par Ordre du Roi pendant les Années 1837, 1838, 1839, 1840, sous le commandement de M. J. Dumont D'Urville, Capitaine de Vaisseau. Histoire du Voyage, Tome VIII. pp. 175, 176.

regions may be briefly considered. While there is a great lack of continuous meteorological observations in the southern seas — absolutely none having been taken on land, near or within the Antarctic Circle — enough is known to justify the statement that the temperature conditions there are very different from those which prevail in similar high latitudes at the North Pole. There we find a warm summer and a winter of intense cold. In the Antarctic region, on the other hand, the temperature rarely, even in midsummer, rises above the freezing-point. Thus the observations taken on board the "Erebus," during the month of February, 1841, between the parallels of 69° and 77°, gave as the mean of the month 24°.18 (F.). Only once during that time did the maximum thermometer reach as high a figure as 34°. In corresponding Arctic latitudes the mean remains for three months above the freezing-point. For instance, the mean of July at Port Foulke, latitude 78° 18′, was 40°.54; of Van Rensselaer Harbor, 78° 37′, 38°.19; of Port Kennedy, 72° 01′, 40°.12. The mean of the three summer months at each of these stations was 36°.82, 33°.38, and 37°.40: that of the three winter months, —21°.22, —28°.59, —35°.04. In Greenland, as we have seen, the surface of the inland ice in summer is intersected by a network of rivers. The Antarctic ice, on the other hand, is hardly ever spoken of by explorers as exhibiting any signs of melting.

These and similar facts indicate very clearly that the climate of the southern hemisphere is peculiarly an oceanic one. Instead of comparatively warm summers and intensely cold winters, we have — as has already been noticed, in speaking of the climatic conditions of some of the islands in much lower southern latitudes — very cool summers, and winters but very little colder than these. The mean temperature of the year is, on the other hand, believed to be high, as compared with that of the North Polar region, since the comparative mildness of the much longer winter more than compensates for the coldness of summer.*

* See, for an elaborate discussion of the probable climatic conditions in high Southern Polar latitudes, A. Mühry, in Klimatographische Übersicht der Erde, Leipzig und Heidelberg, 1862. Appendix, Chapter entitled "Überblick über die meteorologischen Verhältnisse der Südlichen Polar-Zone, bis jenseits des Polar-Kreises." Also, a review of the glacial and climatic features of both North and South Polar regions, by A. von Woeikof on "Gletscher- und Eiszeiten in ihrem Verhältnisse zum Klima," in Zeitschrift der Gesellschaft für Erdkunde zu Berlin, Vol. XVI. 1881, p. 246. Mühry inclines to the view also advocated by Petermann that there is probably no extensive continental land mass at the South Pole, while Woeikof thinks that there may be, — at least "in the highest latitudes." The latter, while admitting the general fact of a pre-eminently oceanic climate in the southern hemisphere, considers it pretty well established that, south of the parallel of 40°, at least, the mean temperature is higher than in corresponding latitudes north of the equator. If there is a large mass of land at the South Pole itself, however, he does not doubt that as low a temperature will prevail there as in the coldest regions of Siberia.

Such being the facts with regard to the climatic and other conditions in high southern latitudes, we seem to be justified in doubting whether the ice fields of that region are not, as already suggested, more the result of the freezing of the ocean surface than of the conversion into ice of snow which has fallen on the land. The peculiar forms of the Antarctic floating ice masses, not resembling those seen in northern seas and which are known to be icebergs originated from glaciers; their mode of distribution, which appears to be — to a considerable degree, at least — independent of the land; the just doubts as to whether the ocean does not occupy by far the larger portion of the surface within the Arctic Circle; the absence of an ice barrier at the base of ranges of mountains over 10,000 feet in elevation in the highest southern latitudes visited: these, and other facts which want of space makes it impossible here to indicate in detail, form the evidence in favor of the idea that the Southern Polar "ice-cap" — so far as such exists — is simply frozen ocean surface, and therefore cannot be used as illustrative of the conditions of a Glacial epoch *on land*, where only such an epoch can be of importance to the geologist.

As already suggested,* the frozen surface of the ocean, in high northern latitudes, does not seem to give rise to sheets of ice of great thickness, such as those which occur in the Antarctic regions. The reason of this seems to be, that the heat of the Northern Polar summer melts away from the surface as much, or nearly as much, as is added during the winter. The theory of Mühry with regard to these ice masses of the south is, that they are formed by addition of frozen material from beneath. He thinks that they are of great age, and that they are increasing in thickness. This idea of their origin is supported by the evident marks of perfectly uniform horizontal stratification of the ice reported by the different explorers of the Antarctic region. These are of such a character that it does not seem possible that they should be originated by glaciers on land. It is an interesting fact that the "floebergs" of the Nares Expedition, which are masses of salt-water ice of great size and peculiar appearance, and which were so called in order to distinguish them from ordinary icebergs (born of glaciers), are described as having precisely the same peculiar tabular form and horizontal stratification which characterize the Antarctic barrier ice.†

* See *ante*, p. 292.

† See Shores of the Polar Sea, a Narrative of the Arctic Expedition of 1875–6, by Dr. Edward L. Moss, H. M. S. "Alert." London, 1878. This is a folio volume illustrated by large chromolithographs. No. XII. of the series shows the peculiar form and structure of the "floeberg." The writer has searched in vain among numerous pho-

In the first chapter of this volume the reader is presented with a somewhat detailed account of the distribution of snow and ice in the North American Cordilleras, and on the western side of that continent generally; and there is nothing to add here in reference to the occurrence of similar phenomena on the Atlantic slope, or in the extensive regions to the northeast of the Great Lakes. It is not until we pass beyond the Polar Circle, and reach the island groups which lie to the north of the continental mass of land proper, that there can be any question as to snow remaining permanently upon the surface, or forming itself into glaciers. As has been already shown, however, by far the larger part of these islands are not only not the scene of any general glaciation, but they are, even on high ground, to a very considerable extent bare of snow during the summer months.

Enough has been said, as it appears to the writer, in regard to the present distribution of snow and ice throughout the world, to enable the reader to have a fairly complete idea of the climatic conditions by which this distribution is governed. All that remains to be done, before passing to the next division of our inquiry, is to call attention to the bearing of the facts which have been presented in this section on certain points which are of special importance in connection with the problem before us. There are, however, other points which will not be touched upon at this stage of our discussion because they can be brought forward in a more effective manner in a succeeding section, after some of the phenomena of the glaciation of a past epoch have been laid before the reader. These will be presented very succinctly, with such comments as may seem desirable for the proper appreciation of their bearing.

The present discussion may be opened by a few words in regard to the general subject of precipitation, in addition to that which has already been given in the preceding chapter. It is especially desirable that a clear idea should be had of the climatic conditions requisite in order that snow may accumulate in any particular region in large quantity, and of the manner in which this superabundant supply is converted into ice.

It is well understood that precipitation takes the form of snow when it falls through or comes in contact with air chilled below the freezing-point. It would appear that to many who have written extensively on glacial

tographs of ordinary icebergs, taken in lower northern latitudes, for any showing this distinctly stratified appearance. Stratification is indeed visible in some; but of an entirely different character from that of the floeberg, it being finer and curvilinear; just such, in fact, as would be expected to occur in fragments of large glaciers.

topics this was the only meteorological fact necessary to be remembered in connection with their discussions. Cold converts the moisture in the atmosphere into snow, therefore cold regions will be regions of great snow-fall, and the more intense the cold the more abundant the supply. Nothing can be farther from the truth than this. The moisture must first be present before it can be congealed; and the evaporative agency, by means of which it has been raised into the atmosphere, is heat. As already sufficiently explained in the preceding chapter, the greater the heat the greater the amount of evaporation, other conditions remaining the same. The moisture, once taken up, may be carried to a great distance before it becomes condensed again, and whether it shall fall in the form of rain or in that of snow depends on the direction and force of the air currents and the climatological or topographical conditions prevailing in the region towards which the moisture-laden air masses are borne.

It has already been shown, with sufficient detail, how the exterior portions of the continental masses receive more than their share of the water abstracted from the ocean; and how, in consequence of this, the interiors of large land areas are comparatively dry. It has also been explained how it is that very extensive regions unfavorably situated with regard to the prevailing winds, and under the lee of high mountain ranges, may be thus rendered so arid as to be almost uninhabitable. That which is true where the precipitation is all, or in large part, in the form of rain, is equally so where the mean temperature is so low that snow predominates. Vast areas in Central Asia, as we have seen, have a very low mean winter temperature, nevertheless they are but very scantily supplied with snow. The same is true of the ranges of the Rocky Mountains and the Great Basin. The prevailing moisture-bearing winds being westerly, the Sierra Nevada is the recipient of a very large snow-fall; while the ranges farther east, some of which are nearly or quite as high as the Californian Sierra, receive but a small quantity of moisture either in the form of rain or snow. Still some aqueous vapor does get carried over into the Great Basin, and, becoming condensed into snow on the summits of the ranges, remains during more or less of the summer, and by its melting furnishes water enough to prevent the region from being one of utter sterility.

It is a clearly established fact, therefore, and abundant illustrations of it have been furnished in the preceding pages, that cold alone is not sufficient to bring about precipitation, whether it be in the form of rain or of snow;

other favorable conditions must concur with the presence of cold, in order that the snow-fall may be large in any particular region; and, since cold diminishes evaporation, it is plain that lowering the mean temperature of the earth will have a powerful influence in hindering the occurrence of that peculiar combination of circumstances which is needed in order to bring about a large amount of precipitation, whether in the form of rain or snow. As a proof of this — the necessary result of the climatic and topographical conditions prevailing throughout the earth — it has been shown in the present section that areas of excessive cold are abundantly enough spread out over the surface of the globe; but that regions in which snow lies permanently on the ground, and becomes exposed to the conditions necessary for its transformation into ice, are very much less extensive.

In the opinion of the present writer, we are justified in drawing, from the facts here presented, the inference that we have no right to assume as having existed during the Glacial epoch a period of intense cold, or even a lower mean temperature than that now prevailing over the earth. Abundant precipitation being demanded for the formation of extensive snow-fields and large glaciers, and that abundance being dependent for its existence primarily on a high temperature, it is evident that we can never have any such thing as a general glacial period extending over the whole earth. If, on examination of the facts, it should appear that certain regions were once more or less heavily glaciated, where now snow and ice no longer exist, or, if existing, are present in much diminished quantity, we shall not be justified in supposing that this condition of things can be accounted for by simply lowering the mean temperature of the earth: on the contrary, a generally higher temperature, being attended by more copious precipitation, is *a priori* just as likely to be a favorable condition for producing the demonstrated effects; while the local diminution of temperature necessary for causing that precipitation to take the form of snow instead of water is to be sought for in causes acting only over certain limited areas, and only in those localities where reliable observations show that such effects actually did take place. In short, the only general Glacial epoch which can possibly occur on the earth will be that in which refrigeration has advanced so far that "Polar ice-caps" have been formed by the freezing of the ocean, at both poles. From that point of view it is not impossible that we have already entered upon the Glacial epoch, and it is not in the power of any one to say that there is not now more snow and ice upon the earth than there has been at any former time; or, in other words, that we are not now nearer a period of "general glaciation" than we have ever before been.

It cannot fail to have been noticed in the synoptical view of present glaciation which has been presented in the preceding pages, that glaciers and permanent snow-fields are the exclusive appendages of mountain slopes and high table-lands. Nowhere on earth, not even in the highest northern latitudes, can a glacier be seen which has originated on level land, and developed itself independently of some adjacent higher region. That this should be the case in low latitudes, it is very easy to understand; it is because in such we cannot have a temperature sufficiently low for snow to fall or exist at all, unless we rise to a certain elevation above the sea-level. That it is true also for high latitudes, where the mean temperature at the sea-level is below the freezing-point, and where other conditions seem such as to favor the formation of glaciers, is a fact not so easily explained. It is, however, one of so much interest in connection with theories of the Glacial epoch that it merits special examination, and we may perhaps best arrive at a clear idea of the nature of the problem, by endeavoring to answer the question: Can glaciers originate on level land under any circumstances? That they do not, at present, will be admitted, and the point is, What possible modification of prevailing climatic or other conditions would permit this to take place? To obtain an answer to this important question, it will be necessary first to ascertain what is the essential difference, as respects the accumulation of snow and the resultant formation of ice from it, between level areas and the summits and slopes of mountains. The difference we conceive to be simply this: that elevated regions may be, and often are, regions of cold, and at the same time of large precipitation, while flat regions are not. That this should be the case clearly results, as it appears to the writer, from the general principles in regard to precipitation to which our attention has been turned in the preceding chapter. That it is so, seems evident enough when we survey the entire area covered by ice and snow throughout the world. Over those immense tracts of low land which lie near and beyond the Polar Circle, in both Asia and North America, the snows of winter do not accumulate in such quantity that the next summer's sun does not entirely melt them away. On the high plateaux of Central Asia, where the mean temperature is very low, the snow-fall is nearly all intercepted by the adjacent ranges, which rise still higher. A plateau which was itself the highest land of any region might become deeply covered by snow, if exposed to receive a large enough amount of precipitation, as we have seen to be the case in the Scandinavian Range. There the high and comparatively level summit has in places large areas of permanent snow or *névé;* and if the precipitation were considerably increased, no doubt these areas would be correspondingly enlarged, for the mean temperature is sufficiently low to cause all the precipitation to take the form of snow, over a much larger part of the range than is now permanently covered; only, as we have seen,* the heights of land nearer the ocean from which the moisture-bearing wind comes cut off the precipitation, which is not large enough to hold out so as to reach more than a very short distance inland.†

Reasoning from analogy, we may therefore suppose that if a low level area was cold enough to receive its precipitation in the form of snow, and at the same time was so situated that the winter snow-fall should be larger than could be melted away by the summer's sun, there would be an accumulation of snow or ice. Which of the two would finally cover the country the prevailing climatic conditions must determine. Here a few words may properly be introduced in regard to the conversion of snow into ice, since that is a process which directly connects itself with the question before us.

Ice may be and is formed in nature in two ways: either by direct freezing of water, as in the case of the ordinary congelation of the superficial water of rivers, lakes, or ponds, or even of the ocean surface; or by the transformation which snow undergoes when exposed to suitable conditions after it has fallen upon the ground. The writer's long and careful examination of snow and ice masses in various climates and positions leads him to the conclusion that in nature ice is hardly formed at all from snow except through the intervention of water. This water may be derived directly from rain-fall, or it may be furnished by the rapid melting of the superficial layers of snow. In some regions, as for instance in the Alps, it is the rain-fall which is chiefly concerned in bringing about the transformation in question; in other countries it is — at least in large part — effected by the saturation of the mass by the water derived from its own melting. That this must be the case seems to be clearly proved by the manner in which the dry snow of the upper regions becomes changed first into a slightly granular mass, then into decided *névé*, and finally into well-characterized glacier ice. The position of the *névé*

* See *ante*, pp. 288, 289.

† The difference in the amount of precipitation on the two slopes of the Scandinavian Range is very great. See Krümmel's Rain-chart of Europe, in Zeitschrift der Gesellschaft für Erdkunde zu Berlin, Band XIII. 1878.

line on mountain slopes is clearly dependent on climatic conditions, and not on the pressure to which the mass may happen to be subjected. The phenomenon of the conversion of snow into ice by imbibition with water and subsequent freezing is one which occasionally takes place on a large scale and over an extensive area in our own land and climate. A deep snow-fall may in a few hours be entirely changed to ice, and those who live in New England have had, within a few years, occasion to observe this process occurring on a large scale.*

That mere pressure alone will not, as maintained by Tyndall and others, change snow into ice *in nature* — whatever it may do in the laboratory — seems proved by the conditions presented by snow masses in regions where rain never, or hardly ever, falls. For instance, accumulations of snow miles in length and hundreds of feet in depth lie from year to year on the slopes of Mount Shasta without exhibiting the slightest sign of conversion into ice. The climate is too dry to allow any moisture to remain in contact with the snow long enough to allow of imbibition. Neither does it ever rain in summer; and in winter all the precipitation, which is extremely abundant, is in the form of snow; so that the snow remains dry, and never shows any tendency to become converted into ice. It is only on the north side of the mountain, directly under the summit, where the prevailing winds would carry what little moisture is formed, and allow it in part at least to become condensed, that small masses of ice exist; these may, however, be the relics of the once largely developed system of glaciers occurring on the summit and western slope of the Sierra Nevada, formed when climatic conditions were different from what they are at present: it is by no means certain that, if removed now, they would be replaced by formation out of the snow-fall of the existing period.

Glacier ice is not simple ice, but a mixture of ice and water, and it is to the presence of the latter that the whole mass owes its flexibility. The larger the amount of water, other things being equal, the more easily the glacial mass moves. When the water increases so as to get the upper hand, the ice gives way with a rush, and becomes an avalanche, as is well known to be the case with certain glaciers in Tyrol and the Caucasus. The extreme variability of the rate of motion of different glaciers coming down from the inland ice of Greenland is due to the different amounts of water which they have

* During the winter of 1875 – 76 there was a marked instance of this kind; the surface of New England from Connecticut to beyond Massachusetts became covered with a continuous sheet of ice.

imbibed. Where rivers are running over its surface, as is the case in midsummer, then it is no wonder that we find the ice itself moving at the rate of twenty meters a day, or perhaps even much more in some localities. In the winter, on the other hand, the motion, if not entirely stopped, seems to be nearly so, as we may infer from the observations made during spring and autumn. That this retardation of the flow of the ice during the cold season should be more marked than it is in the case of the Alpine glaciers is not to be wondered at, when we consider the great length of the Polar winter.

In view of what has been stated in the preceding pages, we consider it not unreasonable to suppose that climatic and topographical conditions might possibly so have arranged themselves, at a former epoch, that there should have been in certain regions an accumulation of ice or snow, or of both, independently of any elevation of the land or range of mountains. To bring this about, a low mean temperature and a large amount of precipitation would be required, a condition not sufficiently realized at the present time except on high land. The nearest approach to the desired combination is found in certain parts of the Polar regions, as has been shown in the preceding pages. But the conditions of the Polar lands and seas are such that it is extremely difficult to assume their existence in other zones, with any conceivable arrangement of land, or modification of climate. These circumstances must be kept in mind while discussing the possible or probable former spread of ice and snow over parts of the earth's surface where they do not now occur. In the course of that discussion the application of the facts and considerations which have been brought forward in the present section will be found.

SECTION III. — *Recent Changes in Glacier Regions.*

The object of the present section is to describe and explain the changes which are now taking place in glacier regions, or, in other words, to indicate what variations in the size and position of the ice masses of various countries have occurred within comparatively few years, and especially during the past half-century. The aim in view in doing this is, to throw light on the nature and potency of the climatological causes which have been influential in bringing about that much greater extension of the glaciers which, as we shall see in the next section, at a former epoch characterized certain regions of the earth. Knowing where ice and snow occupy the surface permanently at the present time, it is natural to ask what changes, if any, take place either from year to year, from decade to decade, or from century to century, in the amount and distribution of this frozen precipitation. Should it appear, on examination, that such changes do occur; and that within the lifetime of a single observer, or sometimes indeed within a year or two, the amount of these variations is very considerable, it would seem that the question would immediately be asked, Are these changes not necessarily the result of variations in the meteorological conditions, and may we not by examination of the records of temperature and rain-fall, so accurately kept during later years, be furnished with some information as to the amount and character of the climatic changes accompanying these comparatively rapid fluctuations of the glacial masses, by which we shall be assisted in forming an opinion as to the nature and magnitude of those more important changes which we are led to suppose must have coexisted with those greater developments of snow and ice, the epoch of which is commonly designated as the Glacial?

A small amount of information as to what is going on at the present day in glacier regions makes us at once acquainted with the fact that glaciers are by no means stable things, that they are subject to changes of dimensions, and that in some cases these changes take place with extraordinary rapidity. It is also generally recognized by those who have made even a superficial acquaintance with the Alpine ice-fields that they are and have been, since they first began to be noticed and studied, subject to oscillations of considerable amount; these, however, are by glacial geologists not usually considered to be in any way connected with phenomena of the Glacial epoch, but are supposed to be merely temporary fluctuations, it being assumed, as a matter of course, that if any glacier is now diminishing in length and thickness it will, at no distant date, acquire its former dimensions.

It may be at once stated that by far the most interesting and important fact which presents itself to us on entering this branch of our inquiry is this: that during the last half-century all those glaciers throughout the world with which we are sufficiently well acquainted to be able to speak positively as to their changes of dimensions have been more or less rapidly and regularly diminishing in size. This fact will be first considered, and as complete a general statement made in regard to its main features as the material at hand will permit. Some account will then be given of former oscillations of the glaciers in those regions in regard to which we are so fortunate as to have some records, scanty as they almost invariably are: for attention to glaciers and glacial phenomena is, almost everywhere, a thing of extremely modern origin. And in farther pursuance of the same line of inquiry, we shall make a brief statement of the nature of those very rapid changes which occasionally take place, and to which certain well-known glaciers are especially liable, although these changes evidently depend on very local conditions, and, however interesting to those who are exposed to the often most disastrous consequences of these misbehaving masses of ice, are by no means of so much importance to us, from the point of view of the present investigations, as those slower oscillations or changes which are due to the agency of more general causes, and may therefore be expected to throw light on the problems with which we are occupied.

One would suppose that so important a fact as the general recession, during several successive decades, of the glaciers would, in the Alpine regions at least, have excited the greatest possible interest, and that a large amount of information, statistical and other, in regard to it would already have become accumulated. Considering that the members of the various Alpine Clubs, French, German, Austrian, and Italian, may be numbered by thousands, it would seem as if facts of the kind here desired would have been precisely those which would have been most zealously gathered. On examining the publications of the various clubs, however, the data are found to be very meagre. The principal facts, however, can be given with sufficient detail for our purpose, particularly as the present writer has had the advantage of repeated visits to various portions of the Alps, during the last two of which, in 1879 and 1881, his attention was specially directed to procuring information in regard to the condition of the glaciers as to advance or recession, and particularly in the eastern portion of the range from the Bernina Group eastward.

The Alpine glacier group where the present recession has apparently been most marked, and where it first began to be noticed, is that of Mont Blanc. Here, too, the most complete records of the movements of the ice have been kept, so that a pretty good idea of the general character of the change can be gathered.*

* The record alluded to is that of M. Venance Payot, who in 1879 published a *brochure* entitled "Oscillations des Quatre Grands Glaciers de la Vallée de Chamonix," embracing the observations of thirty years. This volume the present writer has not been able to procure, but information supplementary to that contained in this work appears in the Annuaire du Club Alpin Français for 1880 (published in 1881 — the seventh of the series). From this source and from various communications made by other Swiss geologists, the statements given in the present section have been compiled. There is more or less discrepancy in the dates, as might be expected, but the general facts are clearly indicated.

The essential fact is this, that all along the great mass of mountains which extends through Southern Europe to the Caspian Sea, including the Pyrenees, the Alps proper, and the Caucasus, the glaciers have been diminishing in size with considerable regularity during the last few years. While, however, the recession seems now to be general, and to extend through from the Atlantic to the Caspian, it is certain that it did not begin through the whole region at precisely the same time. Indeed, portions of the Alps not far distant from each other took up the receding movement at quite different periods.

Of the four great glaciers near Chamouni — des Bois, des Bossons, du Tour, and d'Argentière — the first one mentioned seems to have been receding during the longest period, and to have been most shortened. According to Venance Payot, it had lost in length from 1818 up to October 8, 1880, no less than 1,250 meters. Between the 25th of March and the 3d of June, 1880, or in seventy days, it had receded ten meters. Between June and October of that year it remained nearly stationary. The Glacier d'Argentière has diminished during the past few years more rapidly than any other of the four, and between June 28th and November 15th, 1880, it had receded a little more than forty meters.

The Glacier des Bossons had diminished in length between 1817 and June 12, 1874, no less than 682 meters, and its recession at that time was becoming more and more rapid, having been as much as twenty-seven meters a year, on the average, between 1862 and 1874. This glacier, in 1880, had become very irregular in its movements, one side receding and advancing irregularly, and not synchronously with the central portion. M. Payot remarks that during the month of May, 1880, the glacier seemed to be undergoing some internal movement which went on without ceasing. Rolling and cracking sounds were heard continually, and masses of ice were constantly falling from the front of the mass, so as to render access very dangerous.

The shrinking of the glaciers on the north slope of the Mont Blanc system seems to have been first noticed during the years 1818 to 1828; from that latter date on, it began to be recognized as general. At the close of the season of 1880 M. Payot seemed satisfied, from various appearances in and about the glaciers of that region, that the period of recession was about to come to an end, and that a forward movement was soon to begin. He says: "The frequency of avalanches, the formation of seracs more imposing than any seen during many previous years, the enlargement of the crevices, everything indicates that the great ice currents are about to enter on a period of increasing activity."

This, however, was certainly not the case during the succeeding year (1881) in the eastern portion of the Alps, visited by the present writer at that time. All about the Gross Glockner and the Gross Venediger, the appearance of the glaciers indicated continued shrinking, and the testimony of the guides was to the same effect. The changed appearance of the mass of the Orteler Spitz at that time, as contrasted with the much greater body of snow and ice exhibited on that mountain when studied by the writer in 1844, was most striking. All the photographs of glaciers taken in this region within the past few years show the same characteristic features of recent shrinkage, so easily recognized by those who have had their attention turned to these things.

So, too, in the Bernina Group, as examined by the writer in 1879, the proofs of recession were everywhere apparent. Of the date of its commencement in this region no positive information could be obtained; but the rate of recession of both the Morteratsch and Rosegg glaciers was stated by those best qualified to know as being very large.*

The glacier of Gébrulaz, in the Tarentaise, appears from the account given by M. Borrel, President of the Tarentaise section of the French Alpine Club,† to have been diminishing for the past 149 years. During that period of time this glacier has retreated no less than 1,422 meters. During the years from 1730 to 1830, the average rate of recession was 3.20 meters a year; from 1830 to 1879 it was much more rapid, being as much as 22.48 meters. These results appear to have been reached by comparison of various maps and documents brought to light on the occasion of a legal investigation of claims to surface left uncovered by the retreat of the glacier.‡

In the number of the Alpine Club for August, 1881, Mr. C. E. Mathews, late President of the Club, remarks as follows: "The Swiss glaciers continue their unfortunate retreat. No one who has visited the Alps with any regularity during the last twenty years can have failed to be struck with the

* The writer was most vividly impressed here, as elsewhere in the Alps, in the examination of the abandoned beds of the glaciers, to see how striking were the proofs everywhere displayed of the inability of the glacier to remove even the smallest rock obstacle in its way.

† Annuaire du Club Alpin Français, 6me Année, pp. 678 – 680.

‡ Interesting questions are being raised in various places as to legal rights to ground left uncovered by the recession of the glaciers.

extraordinary diminution in their size; with some of them it is not only retreat, it is catastrophe. The amazing reduction of the high ice-mark calls for special observation. What is the cause of it? Whether, as Mr. Stephen suggests, the glaciers are indignant at the increased rush of tourists, and retire sulkily into their hidden fortresses, or whether the enormous reduction in the acreage of Alpine forests causes a drier atmosphere, and consequently a diminished snow-fall, I shall leave for you to determine."*

The diminution or increase in thickness of any glacier during a given period is much less easily determined than any corresponding change in its length. M. Payot stated that up to 1876 the average diminution of the Chamouni glaciers in length was about 1,000 meters, and in thickness about 100 meters.

The glaciers of the Bernese Oberland appear to have begun their decrease later than those of Mont Blanc, as did also the glacier of the Rhone, which is said by C. Dufour to have commenced its recession about 1855 or 1856.† As far as known to the present writer, up to the end of last year the recession had become universal throughout the Alps, and there were nowhere decided indications of a change to an advance.

That the recession of the glaciers is not confined to the Alps, but is also most decidedly manifested in both the Pyrenees and the Caucasus, is a statement in regard to which the evidence, although not as full as in the case of the Alps, is sufficiently convincing. In reference to the Pyrenees, M. Trutat, a member of the French Alpine Club, writes as follows: "In 1809, Charpentier measured the elevation above the sea-level of the foot of the Maladetta glacier, and found it to be 2,286 meters. In 1876, I repeated this measurement, and found the terminus of the ice to be at the elevation of 2,550 meters, thus proving the fact of the recession of the glacier amounting to a vertical distance of 274 meters in sixty-seven years."‡

M. Trutat adds to this observation the following remarks: "Pour ma part, depuis que j'explore les Pyrénées, je vois, pour ainsi dire, les glaciers fondre sous mes yeux, et dans la vallée du Lys, et dans la région de l'Oo le retrait est effrayant."§

* Journal of the Alpine Club, Vol. X. p. 260.

† Bulletin de la Société Vaudoise des Sciences Naturelles, Série 2, Tome XVII. pp. 422–425.

‡ Annuaire du Club Alpin Français, Année Troisième, p. 483.

§ Professor C. Dufour says, after speaking of "the general retrograde movement which has become the rule in all the Alpine regions:" "In 1878, at the Scientific Congress in Paris, I had the opportunity of conversing on this subject with several French *savants*, and learned from them that the glaciers of the Pyrenees were in the same

Similar facts in regard to the recession of the glaciers of the Caucasus are reported by various authors, and especially by Abich, the veteran explorer of that range, who, in 1879, informed the present writer that there could be no doubt of the fact that a general recession was going on at that time. In an article on the glaciers of the Caucasus published in 1877, Abich makes the following statement, which is also valuable as evidence with regard to the diminution of the Alpine ice-masses: "A secular period of recession [Rückzugsperiode] of the glaciers of the Caucasus, and first of those of its western half, became evident, and seemed to resemble both in character and amount the same phenomenon which has occasioned so much surprise within the past fifteen years, in both the Eastern and Western Alps. In 1849 an uncommon forward movement of the glaciers in the vicinity of Elburuz was a noticeable fact. At that time I saw the glacier of the first order of magnitude in the Baksan Valley push forward its former terminal and lateral moraines, on which pine trees of a hundred years in age were growing. . . . . At the same time a similar condition of advance was noticed in the Aletsch glacier, the longest of all the ice-streams of Switzerland. The later occurring and continuous recession of the Baksan glacier began to be noticed during the years from 1860 on. That all the glaciers from Elburuz east to Kasbek have joined this receding movement, and that they all, including those which belong to the mass of Elburuz itself, are still diminishing, I am able to state positively, because my yearly repeated excursions to the higher parts of the northwestern region of the Caucasus gave me an opportunity to make comparisons and measurements at the same points which I had visited many years before. . . . . From my own observations, made in the years 1867, 1872, and 1876, I had become aware of the constantly increasing body of facts indicating recession which were displayed by the glaciers of the Engadine, Mont Blanc, and the Bernese Oberland, and I was fully convinced of the entire harmony in the Alps and Caucasus in respect to the physical character of the changes connected with this recession. All the information which has been furnished since that time by competent observers confirms the fact that the diminution of the glaciers is still going on in the Pyrenees as well as in the Alps." *

case ; all of them had diminished, and some had actually disappeared." Bulletin de la Société Vaudoise des Sciences Naturelles (2) Vol. XVII. pp. 422–425.

* Ueber die Lage der Schneegränze, und die Gletscher der Gegenwart im Kaukasus, von H. Abich. Mélanges Physiques et Chimiques, tirés du Bulletin de l'Académie des Sciences de St. Petersbourg, Tome X. pp. 643–645.

In the same article, Abich remarks that he is unable, from personal investigations, to assert that the same condition of things, as to recession of the glaciers indicated for the western half of the Caucasus, prevails in the eastern portion of that range. He thinks it highly probable, however, that such is the case; at all events, that is the general opinion.

In another article on the Caucasian glaciers,* the same author gives the amount of recession of the Baksan glacier between the years 1849 and 1873, as 600 feet; but in what year after 1849 the backward movement began he was unable to state.

The evidence here presented seems to be sufficient to justify the statement previously made, that a diminution of all the glaciers of the great mass of mountains extending between the Atlantic and the Caspian has been going on for several years; that this change was not begun at the same moment throughout the whole length of the more or less connected ranges; but that it appears to have been first noticed as a fact of importance in the region of Mont Blanc, and not until a considerable number of years later in other regions east and west. It is also true that, although the statement had been repeatedly made by various writers that this recession was about to come to an end, and to be succeeded by a period of advance, such had not been the case up to the end of the year 1881.

That there have been oscillations of the glaciers of the Alps during the historical period, however, and that the present condition of recession has been preceded by others of advance as well as retreat, is a well-known fact, although numerical data are almost entirely wanting. It is the belief of the present writer that the glaciers of the Pyrenees, Alps, and Caucasus have been gradually retreating since the time of their greatest extension, and that there may have been many oscillations in the course of this general recession; but that, on the whole, diminution has had the upper hand of advance, and that the mass of ice and snow on the ranges of Southern Europe is gradually growing smaller: a statement which would, if true, be entirely in harmony with what has been set forth in the preceding chapter. It is a fact, however, that most geologists seem to look upon the "Glacial epoch" as something long since gone by and done with, and to consider the climatological condition of the present day as entirely disconnected with that which happened during the "ice age," but this is not the result at which we have

* Bulletin de la Société Impériale des Naturalistes de Moscou, Tome XLVIII. (No. 3) p. 92.

arrived in studying the subject: on the contrary, we have found everywhere evidence of continuity and harmony in the action of the causes effecting climatic change, and nothing at all to favor the opposite and popular idea of irregularity and violent alternations of change. As far as the present writer can make out from repeated examinations of the Alpine regions, the disappearance of the ice of the "Glacial epoch" is not something which took place a long time ago, but something which is now going on. But, as we have seen with regard to the diminution of the former lacustrine basins of various desiccating areas of the earth, that this has not gone on with regularity, but has been subjected to many oscillations, so we have every reason to believe that the same thing is true of the glaciers.

In regard to the fact of oscillations of the Alpine glaciers having taken place in former times, the information is somewhat abundant, but, unfortunately, far from precise, so that it is quite impossible to draw any other definite conclusions than those which have been already presented. Sometimes the advance in certain regions has been so rapid as to excite the greatest alarm among those living in the neighborhood;* at other times the recession has attracted an equal amount of attention. At the present time it is the decrease of the glaciers which is looked upon as a misfortune, for the money value of the picturesque element in the Alps is now universally recognized by the Swiss.

Gruner devotes a chapter of his work, published in 1760, on the ice-mountains of Switzerland, to what he calls the accidental events [Zufälligkeiten] of the glaciers. A large part of this chapter is taken up with the subject of their oscillations, and it is evident that at the time of the appearance of the work the mountaineers of the Alps were generally complaining of an advance of the ice. An attempt is made to give a chronological statement of the behavior of the Grindelwald glaciers; but, unfortunately, there are not given any even approximate measurements of distance covered or left bare during the various oscillations. Most of the statements are based on comparisons of landscape views taken at various times, and, of course, the uncertainty of such evidence is very great. The strong impression left on the mind of Gruner was, that the glaciers were, on the whole, gaining in dimensions, and he gives reasons, satisfactory to himself, perhaps, but to us, at the present day, quite unintelligible, why this should be so.

* In or about 1690 the inhabitants of Chamouni sent for the Bishop of Annecy to try whether he could not arrest, by his prayers, the forward progress of the glaciers. They did recede immediately after the Bishop's visit, to the extent of an eighth of a league.

It being evident that the ice masses of Southern Europe are diminishing in size, the question naturally arises whether this is also the case in the other great glacier regions of the world, especially in the Himalayan and the Scandinavian ranges. Here, however, we meet with a difficulty. These distant and rarely visited regions have had their glacial features explored with so much less detail than have the Alps, the Pyrenees, and the Caucasus, that it is hardly to be expected that much trustworthy information should be forthcoming concerning the changes of the last few years. It is only in the case of mountain ranges which have been accurately surveyed that the means are furnished for accurate comparison from time to time of the changes which may have taken place in the amount of surface covered by snow and ice. That there has been some diminution of the glaciers both of the Himalayan and Scandinavian ranges seems evident; but it is not easy to say, from any evidence as yet furnished, how much of this has been accomplished within the present century, and how much belongs to that indefinite past which to most geological writers is represented by the term "Glacial epoch." More will be said in regard to this point in the next chapter. In the mean time it may simply be added that Professor Dufour thinks he has evidence sufficient to justify him in stating that all the glaciers of the northern hemisphere are participating in the same retrograde movement. This evidence, as presented in the article to which reference has already been made, is, however, extremely vague and unsatisfactory.*

Although the subject is not one intimately connected with the purpose of the present chapter, yet as it throws light on the causes of the motion of glaciers, a few words will here be added in reference to those very irregular ice masses which from time to time move forward with great rapidity, and do great damage by devastating the regions below, either directly, by flooding the country and covering it with detritus, or, indirectly, by causing the formation of a temporary lake, which finally breaks away and sends a flood of water down the valley.

Of this latter class is the Tyrolese glacier called the Vernagt, which from time to time pushes forward with extreme rapidity, combining with another

* For instance for the statement that the recession of the Scandinavian glaciers "has now become general," no other authority is given than that of "a Swede, M. Nyström, who was kind enough to obtain the information asked for." For Greenland it is said that "several people had observed that the glaciers of that country had retreated considerably." Nordenskjöld is reported, also, as having stated that the glaciers of Spitzbergen "had undergone a similar diminution within the past few years." This is in flat contradiction with what this author has himself published since his return from his exploration of that region. (See pp. 335, 336.)

glacier, named the Rofenthaler, and crossing the valley of the Rofen, where it comes in contact with the opposing wall of rock. In this way a dam is formed, by which the waters of the stream are kept back until they have accumulated in sufficient quantity to burst the barrier and overwhelm the valley below. Six such catastrophes are on record as having taken place since about the year 1599, in four of which the damage caused by the giving way of the lake barrier was very great. The average interval between the more important oscillations has been eighty-four years, the interval between two of them varying from seventy-three to ninety-three years. The rapidity of the movement of the Vernagt glacier at the time of one of these periods of advance is very great, it having in one day (June 1, 1845) amounted to as much as 45.51 meters, or fully six feet per hour. The total amount of motion from November 13, 1843, to June 1, 1845, was 1331.4 meters.*

Another celebrated glacier is that of Devdorok, which descends from the northeastern side of Kasbek, in the Caucasian Range. In this case it is the lower portion of the glacier itself which gives way and rushes down in an avalanche of ice, mud, and granite blocks, causing terrible devastation in the valley below. These occurrences take place at irregular intervals, and there appear to have been ten or more of them during the past hundred years. In the case of the Devdorok glacier, the cause of the sudden descent of the mass seems to be simply that it imbibes so much water from the small streams which run into it in its lower portion, that the mixed ice and water becomes so fluid as to be no longer able to hold up against the force of gravity urging it downward.†

That sudden movements of a similar kind take place in the glaciers of other regions, and perhaps not unfrequently, is to be inferred from accounts given by Nordenskjöld of an extraordinarily rapid increase of one of the ice masses on the island of Spitzbergen. This occurrence is thus described by that author: "In the winter of 1860–1861 the previously unimportant glacier [entering the Nordfiord] extended itself out over the moraines and the Russian Hill [a low eminence to the northeast of the harbor in which Nordenskjöld frequently took refuge, and on which a Russian cross had been set up, near a grave] filled up the harbor, and spread itself far out into the

* See Dr. M. Stotter, Die Gletscher des Vernagtthales in Tirol und ihre Geschichte, Innsbruck, 1846; and also a very good *résumé* of the work by F. F. Tuckett, in the Alpine Journal, Vol. VI. pp. 40, 41.

† See, on pp. 324, 325, what has been said in reference to the causes of glacier motion.

sea. It now forms one of the largest glaciers of Spitzbergen, and from it great masses of ice are constantly falling, so that no boat can with safety approach its edge, which is split up by numerous crevices." *

Nordenskjöld also states that in many places on the island the glaciers have been advancing rapidly during the past century, and he especially instances Ginevra Bay, which he thinks will soon become filled up with ice. The cause of this, in his opinion, is to be found in the rapid elevation of the land which seems to be going on.† These instances are here cited because they seem to throw light on the manner in which the character of the ice masses may change, in connection with, and probably in consequence of, orographic changes in the region where they occur.

The facts which have been stated in the preceding pages are full of interest as considered from the point of view of their application to current theories of the Glacial epoch. It being certain that during the past fifty years the glaciers of Southern Europe have been shrinking rapidly — the extent over which this recession is manifesting itself proving that it is no local matter with which we have to do — we are naturally led to inquire what change of climatic conditions has taken place during this time to which this diminution of the ice masses can be reasonably referred. For so marked a phenomenon the records of meteorological observations now taken with so much care and skill may surely be expected to furnish a satisfactory explanation.

Observations of the kind desired for this purpose have been kept up for many years in various parts of the world and especially in Switzerland, the very region where the glaciers have been shrinking so rapidly. There could be nothing better adapted for throwing light upon the causes of this recession than the series of meteorological observations at Geneva and at the summit of the pass of the Grand St. Bernard, made with great accuracy during the whole time that this diminution has been going on; and, what is equally important, these observations have been worked up with the greatest skill and critical acumen, as already mentioned in a previous chapter.‡ These investigations embrace the years 1826 to 1875, or almost exactly that period during which, as we have seen, the recession became general, and had continued, even in those regions where it began last, as much as fifteen or

* Svenska Expeditionen till Spetsbergen och Jan Mayen, Stockholm, 1863-64, p. 77.

† See Nordenskjöld in Kön. Svenska Akademiens Handlingar, Bandet IV. No. 7 (1863), and VI. No. 7, 1866.

‡ See *ante*, p. 227.

twenty years. Back of 1826 Plantamour did not think it best to go, on account of possible errors in the observation.*

If, then, the shrinking of the glaciers of the Alps which has been going on during the past fifty years is a phenomenon resulting from a marked disturbance of the climatic conditions of that region, it could hardly have escaped the close investigation of this eminent physicist and meteorologist. On examining his work, however, we find nothing which will throw any light on the question of this diminution, neither does the author himself suggest anything of the kind. The mean temperature of the fifty years, 1826–75, was found to be 9°.345 (C.). The greatest variations from this were in 1834 and 1851; the former year was the hottest, the latter the coldest of the fifty years, the average temperature for those years respectively being 10°.99 and 7°.85, a difference of a little more than three degrees. The results, on the whole, show no perceptible increase or decrease of mean temperature during the five decades. The mean of the years 1871–75 only varied about two-tenths of a degree from the grand mean for the fifty years. There has been more than once a series of warmer followed by one of colder years, but no regular recurrence or law of periodicity has been detected, neither can any connection be discovered between these oscillations of temperature and the receding of the glaciers. From 1826 to 1834 there was an exceptionally warm period, or seven years above the average with only two cold ones; this was succeeded by a cold cycle, extending from 1835 to 1860, with twenty-two cold years and only four warm ones. Then again came a warm period, with thirteen warm years to two cool ones. In all this we see nothing to justify a constant diminution of the glaciers during the whole of the fifty years, at least so far as temperature is concerned.

If, again, we turn to the statistics of precipitation, or of the fall of rain and snow, we find no more satisfactory grounds for expecting any diminution of the glaciers than are afforded by the temperature figures. The mean annual precipitation, at Geneva, for the years 1826–75 was $815^{\text{mm}}.93$, and the means of the last two pentads, 1866–70 and 1871–75, were almost exactly the same as the grand mean, namely, $815^{\text{mm}}.62$ and $814^{\text{mm}}.40$. The means of the two pentads, 1856–60 and 1861–65, were decidedly lower than this, being

* "Je n'avais pas utilisé dans cette recherche toutes les observations météorologiques faites, soit à Genève, soit dans les environs, mais seulement celles qui, par la nature de l'exposition des instruments, et par les soins apportés dans le contrôle et la vérification des indications fournies par eux, pouvaient donner des résultats comparables entre eux et d'une exactitude suffisante." Nouvelles Études, etc.: Introduction.

respectively 791.46 mm and 761.12 mm; but these again were preceded by two pentads when the mean precipitation was also considerably above the average. For convenience the figures are here introduced for each pentad from 1826 to 1875.

Pentads.	Precipitation.
	mm
1826 – 30	818.02
1831 – 35	724.10
1836 – 40	791.48
1841 – 45	945.40
1846 – 50	848.74
1851 – 55	848.92
1856 – 60	791.46
1861 – 65	761.12
1866 – 70	815.62
1871 – 75	814.40
Mean 1826 – 75	815.93 mm

These fifty years begin, according to the best informed observers, just about the time when the decrease of the glaciers of Switzerland began to be noticed. "Le glacier des Bossons a commencé à reculer en 1818, la Mer de Glace en 1827, le glacier d'Argentière en 1820;(?) et celui du Tour en 1821."* This shrinking has gone on ever since with slight oscillations; on the whole, however, increasing in rapidity, if decrease in length of the glacial masses is to be taken as a standard of diminishing force. But during this time Switzerland has had several periods of dryness and several of increased precipitation, the last two pentads—as before remarked—when the recession of the glaciers was certainly not diminishing in amount, exhibiting an average almost exactly equal to that of the grand mean of the fifty years.

Classing the years in four categories — namely, as "very dry," "dry," "wet," and "very wet" — Plantamour obtains the following results for the order in which they have succeeded each other: —

	YEARS.			
	Very dry.	Dry.	Wet.	Very wet.
12 years, 1826 – 37	5	3	4	0
19 years, 1838 – 56	1	4	7	7
9 years, 1857 – 65	5	1	2	1

The last ten years, 1866 – 75, show no predominance either way, as they

* Annuaire du Club Alpin Français, 1876, p. 573.

exhibit two very dry years, four dry years, and four very wet years. There is no appearance of periodicity in the results of the observations, and nothing which can be brought into harmony with the facts of glacier recession.

M. Gruner, a French geologist, has endeavored to prove that there has been a decrease of the temperature corresponding with that of the glaciers, and to which he considers that this recession may be referred.* This he does by taking quite arbitrarily a certain number of years out of the long period during which this shrinkage has been going on, and showing that for that period the temperature was below the mean. It would be easy to arrive at precisely the opposite result by selecting another series of years, equally with those taken by M. Gruner years of recession of the glaciers, and making similar comparisons. In short his method is not a scientific one, and his conclusions have no basis of fact on which to rest.

The eminent meteorologist, Dr. J. Hann, has recently addressed a note to the chief of the Meteorological Office at London, Mr. R. H. Scott, in reference to the subject with which we have been occupied in the preceding pages. In this communication the following statement is made: "It is very difficult to account satisfactorily for the retreat of the glaciers, and *in fact this has not yet been done*. . . . . It is much to be desired that meteorologists should pay greater attention to this subject than they have hitherto done, as it seems to me that the periodical variations in the volume of glaciers may indicate more precisely (*or* — are a more sensitive indicator of) changes of climate than the observations (? of quantity of rain-fall) made at our meteorological stations."†

M. C. Dufour, who has been much engaged of late years in observations of the Alpine glaciers, thus expresses himself in reference to this subject: "It would, therefore, be a mistake to seek in the last few years alone the cause of that retreat of the glaciers which we can now demonstrate. This would, no doubt, be the right course if the retreat were caused solely by a more rapid melting, but it is quite otherwise if this cause ascends to the very origin of the glacier. Now the latter is probably the case, for meteorological observations do not reveal to us any notable difference between the last quarter of a century and a preceding period. This is why the investigation of the great retreat of the glaciers that we now witness must not be neglected; it is right to watch and trace it to the end in all those countries

* Comptes Rendus, Vol. LXXXII. p. 632.

† Alpine Journal, Vol. IX. 1879, p. 297.

where it has been demonstrated; and the cause of this retreat, if we succeed in ascertaining it, will be an important factor among those which engage our attention in the study of the physics of the globe."*

The results at which we seem to have arrived in connection with the question with which we have been occupied in the present section may be summed up as follows: In all the mountain chains upon which glaciers are developed, and which have been accurately mapped and are at the same time sufficiently accessible to scientific observers, or which are constantly being visited by tourists and their guides, there has been observed a general diminution in the size of the ice streams, so marked as to excite universal attention. This shrinkage has been going on for from twenty-five to fifty years, with slight oscillations, and with an apparent general increase rather than diminution of rate. It has progressed to such an extent that the principal glaciers of the Mont Blanc district are several thousand feet shorter than they were forty or fifty years ago. When we seek to ascertain whether a corresponding recession has been taking place in other less accessible chains, and especially in the Himalaya and the Scandinavian Range, we meet with considerable difficulty, because although the fact of a shrinkage is clearly indicated, we are unable, from want of accurate and continuous observations, to say how much of this has taken place within a few years, and thus belongs to the present phase of glaciation in the Alps, Pyrenees, and Caucasus, and how much of it might be referred to a prehistoric period of recession, and thus be connected with the Glacial epoch, representing in point of fact, according to the popularly received theory, a phase of geological history which began and ended long ago, and not one belonging to the present epoch.

When we examine the records of meteorological observations taken in the Alps during the past fifty years, using only such as can be depended on for accuracy, we find no light thrown on the causes of this recession. That is to say, we have, on the one hand, an apparently pretty constant diminution of the ice masses from the Mediterranean Sea to the Caspian; and, on the other, numerous irregular oscillations of temperature and rain-fall, but no perceptible permanent change, and none in any constant direction during the half-century over which the observations extend. It is true that we have not the means of comparing the average of the fifty years ending with 1875

* Bulletin de la Société Vaudoise des Sciences Naturelles (2), XVII. pp. 422–425. Translation in Popular Science Review, New Series. Vol. V. p. 319.

with that of any preceding period of time, so that the data cannot be considered as complete; but since the recession of the glaciers did not begin over a considerable part of the region in question until perhaps half of the period embraced in the observations had elapsed, it would be reasonable to expect that the two halves of the fifty years would, when compared with each other, show some differences which might correspond with the changing condition of the ice masses: this does not appear to be the case.

It is by no means the intention of the writer to assert that such changes have not taken place: on the contrary, he thinks it hardly possible to conceive of any increase or decrease of the ice masses or snow fields, even of an area of moderate size — and much less of one which embraces the Alps, Pyrenees, and Caucasus — without a corresponding climatic change. All that is wished here to make prominent is the fact that very slight disturbances of the meteorological conditions produce great effects as manifested in the accumulation of snow, its transformation into ice, and the distance to which that ice is able to move from the region where it originated before being converted back to water. There can be little doubt that, in time, observations will be of assistance to us, in this as in other problems of climatological science.

The majority of geologists and Alpine explorers consider the recession of the past half-century as of the nature of an oscillation. They confidently expect that, after a time, the glaciers will advance and reoccupy the ground which they have been losing of late years. In this idea they are, to a certain extent, justified, because it is known that there have been periods of advance and retreat in the Alps — the only glaciated region in regard to which we have historical data in reference to the subject before us. It is not possible, however, to prove that the Swiss glaciers are not shorter now than they have been at any previous time since the period of their greatest extension. There are traditions of the Alps having been once, "during the Middle Ages," very much more denuded of snow and ice than they now are; but those who have studied the subject most carefully do not put confidence in these stories.

The present writer looks on the recession of the glaciers which has been taking place of late years as part and parcel of a general phenomenon of desiccation, as indicated in the preceding chapter. From his own extensive observations along the whole line of the Alps, he believes that the ice and snow do at the present moment cover less surface than they have ever done since the time of the Glacial epoch — that is, of their greatest extension. He also believes that, although the present period of recession may be followed by one of advance, yet, on the whole, ground will be lost, and that in accordance with what we see to be going on all over the world lessened precipitation will continue to manifest itself in glacier regions by a diminution of the ice masses as elsewhere by a decrease of the lakes and rivers, until an equilibrium shall have been reached between the various natural forces which promote and retard precipitation and evaporation. How much ice and snow will remain upon the earth's surface at that time, and how it will be distributed, it is no easy matter to indicate.

SECTION IV. — *The Former Extension of Snow and Ice over Regions not so covered at the Present Time. The so-called "Glacial Epoch."*

In continuing the investigation upon which we have entered, we have next to examine the question whether ice and snow have, at any previous time, occupied a considerably larger area on any part of the earth's surface than they do at present. If this be the case, as may without hesitation be admitted, we wish to state, as concisely as is consistent with a satisfactory development of the discussion here entered upon, where and how extensive the regions are which have in former times been thus differently circumstanced from what they now are: it will then be in order to inquire into the nature and extent of the topographical and climatic changes which appear to have been the efficient agents in bringing about the indicated results.

The phrase "considerably larger area" has been used in the preceding paragraph, as limiting and explaining the kind of change in the amount of glaciation intended to be sought for and explained in the present section. It will be evident from what has already been stated in this chapter that a small amount of change in the size of the area covered by ice or snow in any region could not be considered as of any importance as indicative of a climatic change, much less as characterizing an epoch. The shortening of all the glaciers of Europe within the past half-century, in some cases to the amount of nearly a mile, does not by any means justify us in assuming that we have, in the course of that time, entered upon a new epoch in geology. Any such change, although it be but a small one, is, no doubt, of importance in the immediate vicinity of its occurrence; but it would surely be absurd for the Swiss mountaineer to maintain that a new cycle of geological events has been begun, because the ice which once threatened his cultivated fields has now withdrawn into the recesses of the mountains. It is the case, however, that geologists have in certain regions, as will be seen farther on, been too much inclined to magnify the importance of local changes of condition, limited perhaps to a few square miles of their own immediate vicinity, and to look upon some trifling difference between the two successive members of a group of stratified detrital material as indicative of world-wide changes. All local details of structure are of value and importance from the local point of view; but it is absolutely necessary in geology to generalize from a mass of facts gathered over a wide region, and the theory of the science would make but little progress if the minute modifications of each locality were considered as necessarily to be repeated in exactly the same order, and with similar comparative importance, all over the world.

In preparing the sketch of the present distribution of ice and snow throughout the earth, given in a preceding section, we found an abundance of material ready to hand to enable us to form, except in the case of the Antarctic Polar region, a pretty clear idea of the locality and extent of the areas thus covered, and of the climatic and topographical conditions there prevailing. The facts are easily obtained, and theoretical difficulties do not present themselves when we arrange and explain them. In endeavoring to make out what regions have been at any former time the permanent abode of ice, where now there is nothing of the kind present, we find that we have a much less easy task before us; for we have only the traces which those formerly existing glacial masses have left behind them by which to be guided in our work; and those traces are often of a very uncertain character, not only as originally left upon the surface, but as afterwards having been subjected during longer or shorter periods to all the accidents of weathering and erosion. Hence, the geologist who has had the most experience in studying the character of glacial markings cannot always come to a correct decision as to the nature and origin of the surfaces presented to him in his investigations, so that mistakes are likely to be made even where the observer has the necessary qualifications for his work, and is not hampered in it by prejudices for or against the various theories which have been started to account for the phenomena of glaciation. Thus the size and position of the areas formerly covered by snow and ice are, in spite of all that has been done in this department of geology within the past few years, matters of considerable uncertainty, especially in this country, where much of that which has been written on this class of subjects has come from the pens of those who never had an opportunity of studying regions of present glaciation, and of thus making themselves practically acquainted with what ice is now doing as an agent of geological change. There are those who see the work of glaciers everywhere, in both hemispheres, and at all epochs. Having once adopted a theory of successive changes of climate which renders it easy, if not necessary, to believe that there have been many "Glacial epochs" during the geological ages, and having also convinced themselves that erosion has all been the work of ice, it becomes very easy to recognize in every rounded rock surface, in every accumulation of pebbles and boulders, and in every striated fragment of rock, no matter where or how found, the proof of the former presence of that all-powerful agent, those who protest against ignoring other, and, as it seems to them, more powerful agencies, being looked upon as hopelessly "behind the age."

In the preceding pages of this volume the conditions and circumstances which may and often do lead to mistakes in regard to the former existence of ice and snow have been pointed out with sufficient detail, and instances given where — as it seems clear to the present writer — it is impossible not to admit that prejudice in favor of a current theory has led to misconception of the facts observed.*

In designating the regions which have at some former time been more extensively glaciated than they now are, the writer will endeavor to adhere as closely as possible to facts. Where differing in opinion from those who, having studied the same regions, have arrived at conclusions of another character, he will not seek to conceal the circumstance; and, although space may not admit a full discussion of the evidence, he will endeavor to convince the reader that there are, in such cases, difficulties which at least render great caution necessary, and that there are good and sufficient reasons why the former presence of ice should not be taken for granted, as has often been done with hardly more than a shadow of proof.

We may begin by making the broad statement that there are only two regions in the world where the phenomena and conditions of a former glaciation are of so peculiar a character and on so grand a scale as to give rise to serious difficulties in accounting for the facts and to make it necessary to admit the existence of conditions of climate or topography, or both, considerably different from those now prevailing over the same portions of the

* See *ante*, pp. 10, 11, 47–51, etc.

earth's surface. One of these regions is Western Europe, the other Northeastern North America. Under the former designation are embraced all the higher mountain groups and ranges along the Atlantic and also those which extend east from the Atlantic and north of the Mediterranean to about the head of the Adriatic. It includes the entire Scandinavian Range, the Highlands of Scotland and of Ireland, the Pyrenees, the Alps, and also, to a certain extent, some of the ranges of less importance north of the Alps, particularly the Vosges Mountains, and perhaps the higher summits of Central France. It may seem strange that these different regions should be grouped together; but if the reader will look at a globe and see how relatively near together the various mountains named lie with reference to each other as compared with the entire area of the land of the eastern hemisphere, he will, it is believed, recognize that this is essentially one region, the higher portions of which have been affected by similar causes, and, as it would seem natural to suppose in the absence of evidence to the contrary, at about the same time.

In point of fact the region in question may be separated into two divisions of importance, one of which, however, is of much greater extent than the other. This latter division includes the Scandinavian Range and the regions adjacent to it, extending into Russia on the east and southeast, covering North Germany on the south and a part of the British Islands on the southwest. The other region is that of the Alps, with which may be included the Pyrenees on the west and the Caucasus on the east.

Northeastern North America, as a field of former glaciation, includes an area the limits of which can be but imperfectly defined, for reasons which will be set forth with some detail farther on in the present section. Roughly speaking, it embraces New England, New York, the region of the Great Lakes, and an indefinite portion of the adjacent British Provinces. Of its extent towards the north nothing is definitely known.

In pursuing our present inquiry we have, in the first place, to set forth the facts on which is based the statement just made that the only phenomena involving really difficult problems of past glaciation with which we have to deal are limited in their occurrence to areas of moderate dimensions as compared with the entire land surface of the globe, and situated as defined above. That is to say, the former presence of ice and snow in regions where they no longer exist was a local matter, and not one in which all the continental masses were concerned.

For this purpose we naturally and properly turn first to the largest land mass of the globe, Asia, because it seems unreasonable to start with any other assumption than that the effects of a geological event or period important and general enough to be called an epoch would necessarily exhibit themselves in a manner more or less striking on that continent which contains compacted into one mass more than a third of the land area of the globe. On examining all the facts accessible up to the present time, we do not find that the Asiatic Continent presents us with evidence of a satisfactory character that so much of its surface has ever been covered with ice as to render necessary the assumption of a "Glacial epoch." This, however, is a statement of considerable importance, since, as all must admit, an "epoch" in geology, the conditions of which did not affect a whole hemisphere — the Southern, namely, as will be shown farther on — nor the largest land mass of the globe, would be something very extraordinary. It will therefore be desirable that we should give a *résumé*, at least, of the evidence which, as the writer believes, justifies the assertion that there has never been an extension of the glaciers, or of the area of perpetual snow, over any portion of the Asiatic Continent, sufficiently great to make it necessary to assume the existence of seriously altered topographical conditions, or of other climatic changes than those already shown to have taken place.

Here, however, we must once more call attention to the necessity of keeping in mind the fact which seems to have been clearly established in the preceding section, that a moderate amount of increase or diminution in the length of the glaciers of any particular region has no such significance as would make it necessary to assume that the climatic or other conditions had undergone some special and important change in order that such a result might be brought about. If, however, the theory sought to be established in a former chapter of this work is correct, and it be admitted that a desiccation of the earth is gradually taking place, we may expect to find the glaciers diminishing as well as the lakes and rivers, as has already been suggested when discussing the changes known to have taken place within the historical period in the Swiss and other glaciers.

In this connection another consideration presents itself, as bearing on the question why we could not reasonably expect that the glaciers of all regions should show in the same way or to an equal amount the effect of the desiccation believed to be taking place. This desiccation is accompanied, and in part caused, by a diminution of the temperature, which also must exhibit itself, to a certain extent, in causing the area over which snow falls to become extended, and thus to favor the formation of glaciers. How far these antagonistic forces may have had, in any particular region, the effect to counterbalance each other, it is evidently impossible to say. The difficulty of accounting for the absence at the present time of ice and perpetual snow in various localities where the climatic conditions seem favorable to their existence has been rendered evident by the statements made in a previous section; much more would it be difficult to make out exactly to what extent the causes in question would be likely to have neutralized each other during a former period. But we may, as it appears, pretty safely draw the inference from the facts presented that diminution of precipitation has, on the whole, been a more potent agent than the increase of cold. That being the case, we might expect to find that, as a general rule, the glaciers in every part of the world where they exist have been diminishing in size during later times. We need not be surprised if it appears to be the case that in some regions they have disappeared altogether. The facts, however, will be first presented — necessarily with extreme brevity — and a discussion of their bearing on the problem before us will then follow. We may, for convenience, begin with High Asia and the chains of mountains by which this region is encircled.*

It so happened that a most extensive and systematic exploration of that portion of the mountain masses of High Asia where we should naturally first look for evidences of a "Glacial epoch" was made by two German geologists, the Schlagintweit Brothers, who had, previous to their work in India, occupied themselves with the study of Alpine geology, and especially with the phenomena of the glacier regions of Switzerland. They had published elaborate works on this subject, and were perhaps as fully prepared to carry on investigations of the kind necessary to determine such a question as that now before us as any persons could be. It is not known to the writer that any other geologists who have made explorations in the Himalaya have had so good a previous preparation for the study of climatic and glacial phenomena. We naturally, therefore, turn to the volumes in which the results of their Indian investigations have been made public, to see what they have to say in regard to the former existence of a "Glacial epoch" in that region. A large part of their work remains unpublished, although twenty years have elapsed since it was finished. Their latest, and, as it would seem,

* See *ante*, pp. 278 - 280.

most authentic dictum on the subject in question may be found in Hermann's "Reisen in Indien und Hochasien."* In this work the author makes the following statement: "In speaking of the meteorological conditions I shall have occasion to show that not only has there never been any trace [keine Spur] of a general period of former much larger ice masses; but that also those of the glaciers of High Asia which descend lowest actually do at the present time reach a lower limit — the climatic conditions in which they occur being taken into consideration — than do those of the Alps."†

The above-stated opinion of Hermann von Schlagintweit seems to be in considerable measure confirmed by the most recent publication of the Chief of Indian Geological Survey, Mr. Medlicott, who says: "The effects, real or imputed, of glacial action on the Alps and elsewhere are so prodigious, that, after accepting some clear cases, such as those quoted in Sikkim and Kashmir, of old moraines at elevations of only 6,000 to 8,000 feet, one is surprised to find that traces of glaciation are not more conspicuous elsewhere in the Himalayas at vastly greater elevations, in Tibet. At least, but slight mention is made of those traces by very competent observers. Dr. Stoliczka may be said to have ignored the subject. Colonel Godwin-Austen, who surveyed the highest regions of Western Tibet, and who from the first paid attention to geological features, only makes casual mention of glacial extension, generally in its least certain form — that of presumed erratics; and Mr. Drew, who enjoyed such exceptional opportunities of studying the ground, and who paid particular attention to this subject, as is proved by his admirable account of the superficial deposits of Western Tibet, makes less distinct mention of glacier extension here than at much lower elevations to the south. . . . . On the whole the published descriptions of Tibetan regions are not what might be expected, had the ground been deeply covered by ice, *as would surely have been the case at a time when on the southern side glaciers reached so low as 7,000 feet.*"‡

In regard to the climatic conditions and former greater development of the glaciers in the southern and southeastern portions of the Himalayan Range the same authority remarks as follows: "It has already been stated that there is, in Peninsular India, so far as is known, no physical evidence of

* Reisen in Indien und Hochasien, by Hermann von Schlagintweit, Four volumes, Jena, 1869 - 80.

† l. c., Vol. III. p. 270.

‡ A Manual of the Geology of India, Calcutta, 1879. Vol. II. pp. 669, 670.

a geologically cold epoch, and some European geologists appear to doubt whether India was affected by the glacial period. There is in the Himalayas abundant and unmistakable evidence of a great extension of the glaciers at no very distant geological date, ancient moraines being found in many valleys of Sikkim and Eastern Nepal at elevations of between 7,000 and 8,000 feet, and distinct traces of glacial action exist in valleys the lowest portion of which is now not more than 5,000 feet above the sea. Moraines have been noticed by Colonel Godwin-Austen farther east in the Nága hills, south of the Assam valley as low as 5,000 feet; in the Western Himalayas perched blocks are found 3,000 feet above the sea, and very large erratics have recently been noticed in the Upper Punjab at much lower elevations."*

It is admitted by Mr. Medlicott that there is no evidence of a "geologically cold epoch" in India, yet there can be no doubt that the glaciers — in portions of the Himalaya, at least — have extended down the flanks of the mountains considerably farther than they now do. It is also apparent that this larger development of the ice was, to a considerable extent, limited to the exterior ranges and did not exhibit itself on anything like the same scale in the Thibetan mountains, that is to say, on those lying farther north and more in the interior of High Asia. This is just what ought to be expected, if the present writer's ideas are correct in regard to the nature and amount of the climatic change by which this former greater extension of the ice on the southern edge of the elevated mass of Central Asia was brought about. It is evident, however, from the extract given above, and italicized by the present writer, that Mr. Medlicott cannot conceive of the ice masses being enlarged in one region while they remained essentially unaffected in another; and yet that would be entirely in harmony with the conditions which have been shown to exist in various parts of the world at the present time. The writer's views receive a very important additional support in the fact that there appears to be no proof of any former "cold epoch" in Peninsular India.

The evidence of former greater extension of the glaciers in other portions of the great system of ranges within which High Asia is enclosed is by no means of a definite character. The eminent Russian geographical explorer, Sewerzoff, claims to have discovered "traces of a Glacial epoch" in the Thian-Schan Range, in the form of old moraines and boulder deposits, which he thinks could only have been produced by glacier action. In one locality

* l. c., Vol. I. pp. 372, 373.

only — in the Kara Valley, namely — does he appear to have noticed glacial striæ. On the whole he supposes that the whole range of the Thian-Schan may have been glaciated to about the same extent that the Alps are at the present time. Moushketoff, another Russian explorer of Central Asia, however, questions the accuracy of the observations of Sewerzoff, declaring that up to this time there is no foundation for the belief of a Glacial epoch in the Thian-Schan.*

In regard to the former glaciation of the Altai Mountains, the information is somewhat meagre; but, so far as it goes, it supports the view that no Glacial epoch has manifested itself in that chain.

Gebler states that in the Altai, the river Katoun, which descends from the highest point of the range, passes through moraines which indicate that there has been a decided recession of the small glacier which exists on that mountain.† B. von Cotta, on the other hand, remarks as follows: "Herewith may be associated the fact of the entire absence of any trace of a former greater extension of the glaciers, and of an ice age corresponding to that of Western Europe. General von Helmersen himself could discover no traces of erratic blocks, or of striated or rounded surfaces, neither could I find the slightest indication of anything of the kind, although I searched for such with care on the foot-hills as well as in the deep gorges of the Altai. This is the more remarkable, inasmuch as the range rises to an elevation of from 7,000 to 11,000 feet above the sea-level, and in the southeastern portion there exist now some small glaciers." ‡

Of the ranges lying to the northeast of the Altai we know but little, and of their former glaciation nothing. In regard to Northern China, however, we have the positive statement of an eminently well qualified geologist, Richthofen, that there are no traces of a former glacial covering [es hier an Spuren ehemaliger Gletscherbedeckung fehlt] in that country.§

From what has already been said in regard to the glaciation of the North Polar regions and especially of Northern Russia, it would seem not at all to be expected that the Ural Mountains should furnish evidence of the passage of an ice sheet over any part of their flanks or summits proceeding from the

* See Извѣстія Императорскаго Русскаго Географическаго Общества, Томъ XII. 1876, p. 222 and XIII. 1877, p. 42.

† Gebler, Uebersicht der Katunischen Gebirge, quoted in Reclus, Nouvelle Géographie Universelle, Tome VI. p. 637.

‡ B. von Cotta, Der Altai, sein geologischer Bau und seine Erzlagerstätten, Leipzig, 1871, p. 65.

§ China, Band I. p. 76.

north. But it is somewhat remarkable that this chain exhibits no traces of any former local glaciation. During the occupation of the Scandinavian Range by the immense masses of ice which are generally admitted to have existed there the Ural remained entirely unaffected. It has no glaciers now, nor has it had them at any former time. Such is the statement of various competent authorities who have worked in this region during later years. Among the most recent information on this subject we have the following from the pen of one whom all will recognize as a competent observer, General von Helmersen: "The Ural appears never to have been occupied by glaciers. Of the many geologists who have explored this chain and described it, not one has observed upon its rocks either polished surfaces, moraines or erratic boulders. Åsar are also wanting."*

Cotta also, in his recent work on the Altai, alludes to the absence of glacial markings or other indications of the former existence of ice in the Ural as a well-known fact.

Considering the marked resemblance of the physical features of the Caucasus to those of the Alps, it is not at all surprising that the two chains should have been influenced in a similar manner with reference to a former greater extension of the glaciers. Indeed, this resemblance is now being exhibited in the marked decrease of the ice masses which has been going on during the past twenty years or more in the Caucasian as well as in the Alpine ranges, as has been set forth in the preceding section. Although it was not until after several years of exploration that Abich became convinced that the glaciers of the Caucasus had once been considerably larger than they now are, yet this fact seems at present to be fully admitted by him, and to have received abundant confirmation from the investigations of Favre. The exact extent of the area occupied by the Caucasian glaciers at the time of their greatest development has not yet been ascertained; but that it was considerable can hardly be doubted.

Favre thus expresses himself in reference to the former glaciation of the Caucasus: "I have already alluded to numerous items of information collected either by M. Abich or myself in regard to this subject. This information is still necessarily very incomplete, and I am not able to furnish a complete picture of the physiognomy of the Caucasus during the Glacial period. Glaciers have left the marks of their passage in the upper portions

* G. von Helmersen: "Studien über die Wanderblöcke und die Diluvialgebilde Russlands," Mémoires de l'Académie Impériale de St. Pétersbourg: VII^e Série, Tome XIV. p. 127.

of the valleys of the Ingour, the Rion, and the Liakhva; still, in spite of the number and importance of the moraines of Upper Suanetia, they do not appear to have been very extensive on the south slope of the Caucasus. The northern side is much richer in erratic deposits."*

There is some difference of opinion between the various explorers of the Caucasus as to the importance of the Glacial epoch in that range; but it appears quite clear that the ancient glaciers had, all through the chain, a considerably less extensive development than those of the Alps at the same period. It is also certain that the ice masses of the Caucasus were entirely subordinated, both as to their position and movement, to the present topography of the chain.†

In regard to glaciation in that part of Asia which lies south and west of the Caucasus, namely in Armenia and Asia Minor, there is little to be said. Mount Ararat, being 17,000 feet in elevation, would naturally be a point of interest in this connection. The snow line on this grand volcanic mass rises to nearly 14,000 feet, a remarkable fact as contrasted with its position on the Caucasus and the Alps, but easily understood when we consider the extreme dryness of the region, where the rain-fall amounts to only ten or twelve inches in a year. There is only one true glacier on this mountain, namely, in a deep, dark valley on its northeast side. This mass of ice is described by Mr. Bryce as being nearly a mile long, and from 200 to 400 yards wide, its lower end coming down to about 8,000 feet above the sea-level. The slopes above the snow line on the shady side of the mountain are mostly "covered with glittering fields of unbroken *névé*, while on the steeper southeast declivity the snow appears chiefly in vast longitudinal beds, filling the depressions between the great rock ridges that run down the mountain, giving it, as Parrot has remarked, the appearance from a distance of a beautiful pointed collar of dazzling white material on a dark ground."‡ The whole of this description of the condition and appearance of the snow masses and ice on Mount Ararat would answer almost exactly for Mount Shasta in California, except that the latter is about 2,500 feet lower than its Oriental brother.

* Recherches Géologiques dans la Partie Centrale de la Chaine du Caucase, Genève-Bâle-Lyon, 1875, p. 101.

† See Favre, l. c., p. 66; also Freshfield, The Central Caucasus and the Bashan, London, 1869, p. 450; Abich, in the various communications in the Bulletin de la Société Impériale des Naturalistes de Moscou, and in the Bulletin de l'Académie Impériale des Sciences de St. Pétersbourg, especially Tome X. 1877, Über die Lage der Schneegränze, und die Gletscher der Gegenwart im Kaukasus; also Tchihatcheff, Asie Mineure, 4me Partie, Géologie, III. p. 486.

‡ James Bryce, in Transcaucasia and Ararat, London, 1877, p. 222.

The only explorer who speaks of any former greater development of the snow and ice on Mount Ararat is Dr. M. Wagner, who says that the glaciers once extended considerably lower down than they now do. He mentions the occurrence of striæ and polished rock surfaces.* Mr. Bryce does not allude to anything of the kind.

The distinguished geological explorer of Asia Minor, Tchihatcheff, declares that no indications of a Glacial epoch are to be found in that part of Asia.† Some observers have thought they had found traces of the presence of former glaciers on the Mount Lebanon Range. Sir J. D. Hooker, the eminent botanist, describes the "Cedars of Lebanon" as growing "on a confused mass of ancient moraines, which have been deposited by glaciers that, under very different conditions of climate, once filled the basin above them, and communicated with the perpetual snow with which the whole summit of Lebanon was, at that time, deeply covered.‡ No proof is offered of the morainic character of the detrital material on which these famous cedars grow; and in view of the entire absence of indications of former glaciation in Asia Minor, it seems hardly probable that the Lebanon Range, in a lower latitude, should have been the abode of extensive masses of snow and ice. Lartet, a skilled geologist, attached to the scientific exploration of this region made under the patronage of the Duc de Luynes, could find no corroborative proof of Hooker's views.§

O. Fraas, an ultra glacialist, sees in the character of the erosion of the old river valleys, or wadis, of Syria, as well as in that of the detrital deposits in general, all through that region, the undoubted work of ice.|| In short, he is one of the geologists who can conceive of no kind of erosion or accumulation of débris, except through the agency of glaciers.

We have thus passed in review all those portions of Asia in which traces of a former more extensive development of snow and ice have been reported to exist; and in view of the facts here laid before the reader it seems that it can hardly be possible that any one should be found who would claim that

* In Reise nach dem Ararat, quoted by Reclus, Géographie Universelle, Tome VI. p. 250.

† Asie Mineure, Géologie III. p. 485: "Tous les phénomènes de la grande période glaciaire semblent faire défaut à la classique péninsule, de même qu'à la Grèce, à la Turquie d'Europe, et à la partie de la Russie située en dehors du domaine des blocs erratiques."

‡ Natural History Review, 1862, p. 12.

§ Bulletin de la Société Géologique de France, Deuxième Série, 1864–65, Tome XXII. p. 458. "Nous n'avons jamais observé de galets striés ou d'autres traces de l'action glaciaire au milieu de ces dépôts."

|| Aus dem Orient, Stuttgart, 1878, p. 114.

the term "Glacial epoch" could be used with propriety to designate the period when the glaciers of a few of the more favorably situated ranges of that continent covered an area at the most not more than a few hundred square miles greater than that which they now occupy. Indeed, when we consider what an immense diminution there has been in the water surface of Asia during later geological times, we might be inclined to admit that there has not been by any means a corresponding decrease of the glaciers, if we did not call to mind that—as already explained—this changed phase of the physical geography of Asia was in part the result of a lowering of the mean temperature, a circumstance which must necessarily counterbalance, to a certain extent, the influences tending to diminish precipitation.

The entire Southern Hemisphere, with its comparatively small area of land, may be disposed of in a few words, since we know nothing positively of the extent of past as compared with present glaciation in the Southern Polar regions. That the amount of snow and ice within the Antarctic Circle is very possibly larger now than ever before has been already stated; there is nothing farther to be said, in the present connection, in regard to those southern lands and seas.

That the glaciers of New Zealand have diminished somewhat in size since the time of their greatest extension seems very clearly indicated by the investigations of Haast and others. Other proofs of the decrease of precipitation in that region are so marked that it would indeed be remarkable if that afforded by the recession of the ice masses were entirely wanting.

In regard to either present or past glaciation in Australia we know absolutely nothing. There is no reason to suppose that glaciers ever existed there. Nearly the same may be said of Africa. Mr. Maw thinks that traces of former glaciers occur in the High Atlas, describing what he considers "unquestionable moraines" in the province of Reraya, at an altitude of 6,000 feet. Although admitting that no scratched blocks or striæ were found, he thinks that there can be no doubt of the morainic character of the detrital accumulations in question.* Other observers in that region have not been able to confirm the accuracy of these views. That there should have been a moderate development of ice or permanent snow on the Atlas Range is not impossible; but, as the evidence now stands, this can hardly be considered as having been proved.

* Journal of a Tour in Marocco and the Great Atlas, by J. D. Hooker and J. Ball, with an Appendix including a sketch of the Geology of Marocco, by George Maw, London, 1878, p. 461.

The evidence of former more extensive glaciation in South America is quite as uncertain as it is in regard to Africa. Darwin observed angular fragments of granite on the island of Chiloe, which he thinks "might formerly have been floated across, on icebergs produced by the fall of glaciers."* It is quite likely that there may have once been a larger development of the ice masses at the southern end of South America; and it would seem reasonable to suppose that the higher portions of the Chilian Andes might have been occupied to some extent by glaciers, at a former period, in harmony with what we have seen to be the case in the high ranges of corresponding latitude north of the equator on the Pacific coast. But no trustworthy observer has reported the existence of unquestionable traces of such former glaciation, so far as known to the present writer.

In a special section of the first chapter of this volume, under the head of "Former Glaciation of the Sierra Nevada, of the Pacific Coast, and of the Cordilleras in General,"† a sufficiently full description has been already given of the traces of the former presence of glaciers on the various ranges on the western side of North America. Since only the highest portions of the most elevated mountain chains were thus occupied — snow and ice covering an area of at most a few hundred out of a million or more square miles of territory within our own borders — it would seem that we can with no more propriety use the term "Glacial epoch" in speaking of the period of the former existence of glaciers in the Cordilleras, than we can in regard to similar occurrences in Asia. There is, at all events, no evidence — palæontological, or of any other kind — that there has been any change of climate on the western side of our continent since the Tertiary epoch, other than that indicated by the ever-increasing desiccation, the proofs of which have been brought forward in a former section. The disappearance of the glaciers is simply another form in which the prevailing dryness has manifested itself.

We have thus passed in review the phenomena of past glaciation in regions where — as it appears to the present writer — it is clear that the conditions are, and have been in former times, such that in order to account for observed facts it is not necessary to invoke the aid of marked climatic or topographical changes, or, indeed, of any agencies other than those in harmony with the ideas maintained in the preceding chapters of this volume.

* Voyages of the Adventure and Beagle, Vol. III. p. 286.

† See *ante*, pp. 23-100.

We may now proceed to consider specially the course of geological events during the Glacial epoch in those regions where, as already suggested, the phenomena and conditions of former glaciation are on so large a scale, and of so peculiar a character as to involve decided changes of climate or topography, or perhaps of both simultaneously. Of the probable extent and character of these changes something will be said after giving a necessarily brief sketch of the facts themselves. And for this purpose it will be convenient to begin with the region of Southern Europe, taking the chain which naturally follows next in order to the Caucasian Range, the former glaciation of which has been already indicated.

It was in the Alps that attention was first called to the fact that ice had once covered a larger area than it now does, and it is there that the phenomena of present and past glaciation have been most carefully observed and studied. The principal facts are indeed easily made out, and are considerably less complicated than those of the Scandinavian Range. The essential point is, that at a former period the present glaciers extended much farther down the valleys than they now do, and the evidence by which this assertion is supported is clear and convincing. There is little in the phenomena presented by the Alpine region of former glaciation which cannot be recognized at once as exactly similar in kind to that which is now going on there, although on a much diminished scale. For instance, it is easy to see that glaciers carry the detritus which falls upon them and deliver it at the point where the ice comes to an end, as a general thing, in an angular form and unstratified. In accordance with this we find along the edges of the Jura, on the side facing the great Swiss plain, accumulations of angular débris piled up just like the frontal moraines of the present day. We see at once that these materials must have been left by a glacier, and on tracing them back to their source, as has long since been done with infinite pains by Guyot and others, we have no difficulty in locating that source somewhere higher up in the Alpine Valley down which we are authorized by all the topographical and other conditions to believe that the magnified glacier moved. In the same way within the Alpine Range itself, at innumerable points, we have the remains of old moraines, both lateral and terminal, piled up in the bottoms of the valleys or along their sides, furnishing the most conclusive testimony that the ice has once occupied the places thus covered with débris which can have had no other than a glacial origin.

It is especially on the south side of the Alps that the phenomena of a former greater extension of the glaciers are displayed with all possible clearness and an entire absence of complication. The Adriatic then occupied what are now the fertile plains of Lombardy, extending up to the base of the Alps, as is proved by the presence of marine fossils in connection with the morainic débris in that region.* The terminal moraines are marked with the utmost distinctness along the edge of the mountains, where the rivers debouch into the plain, and especially at the southern ends of Lago di Garda and Lago d' Isseo. There seems not to be a single feature of the morainic landscape which is not in harmony with that which we see ice doing at the present time, although on a considerably smaller scale, higher up in the valleys of the same range.

The same may be said with almost as much truth along the northern flanks of the Alps. The phenomena are, however, much the most decidedly marked in the western and northwestern portions of the chain. As we go east we find the evidences of glacial extension less conspicuous, and the proofs of the former presence of water in the valleys more and more striking. All through the Tyrolese and Austrian Alps, especially along the course of the Inn and its tributaries, the rivers once ran with much greater volume than they now do, and they have piled up in the valleys and along the northern flanks of the Alps vast masses of débris, stratified and well water-worn, bearing much more the characteristics of water than of ice action, while striated surfaces and true morainic accumulations are by no means as abundant or as decidedly marked as on the western and southern sides of the Alpine Range.

The only difficulty in regard to Alpine glacial geology is to separate clearly the results of the action of water, or of water and ice conjointly, from those brought about by ice exclusively, or in other words, to answer the question, What has been effected which is peculiarly the work of ice and which would not have been accomplished if there had been no glaciers? Those who belong to the ranks of the most advanced glacialists cannot see, even in the fine mud deposited in the valley of the Rhine when that river was much larger than it now is, anything but the result of the grinding of the glacier along its rocky bed. According to them, the crust of the earth would everywhere have remained uncovered by soil, if ice had not ground it

* See Desor, Paysage Morainique, Paris et Neuchatel, 1875, pp. 28–46; Stoppani, L' Era Neozoica, ossia Descrizione dei Terreni Glaciali e dei loro Equivalenti in Italia, Milano, 1880, pp. 131–192; and Rütimeyer, Über Pliocen und Eisperiode auf beiden Seiten der Alpen, Basel-Genf-Lyon, 1876.

off and thus given rise to the débris and soil which now form a superficial covering for the solid rock beneath.*

It is owing to these differences of opinion as to what is the work of water and what that of ice, that opinions vary considerably in regard to the extent of the area covered by the Alpine glaciers at the time of their greatest development, and it will be easily understood that at the present time it is quite impossible to give an accurate representation of the facts on a map. For doing this there will not be available material, until more unanimity prevails among geologists in regard to erosion and the accumulation of detrital material. As an illustration of these difficulties a few remarks may be made bearing on the question whether the ice masses on the northern side of the Alps, in Bavaria, united in a confluent sheet at the base of the range, and made their way over the comparatively level land to the north.

F. Stark made a detailed examination of the north side of the Alps between Salzburg and Munich and has published a map giving "an ideal representation of southeast Bavaria during the Glacial epoch [Eiszeit]." † On this map the glaciers which once occupied the valleys of the Salzach, the Inn, and the Isar are indicated as having at the time of the greatest extension advanced beyond the base of the Alps, to a distance, in places, of three or four German miles, all the valleys on the range above having, as is supposed, been filled with ice to a great depth. The old terminal moraine of this glacial sheet is represented as forming a well-marked topographical feature of the region, extending in grandly regular scalloped forms along the range. A comparison of Stark's map with the minutely-detailed topographical sheets published by the Bureau of the Bavarian General Staff indicates that this line of elevations does not in reality exist; at least, nothing indicating it is laid down on the official map. ‡ Nor did an examination made by the present writer along a portion of the supposed terminal moraine reveal any other topographical features than those given by the government surveys. Large masses of detritus are piled up at the base of the range, which detritus is thoroughly water-worn, and in general distinctly strati-

* "Sans glacier pas de boue glaciaire, la roche à nu partout, et si le glacier ne l'a pas déposée directement, c'est lui qui est l'auteur, le fabricant de cette terre que nous cultivons." Dollfus-Ausset, in Matériaux pour l'Étude des Glaciers, Tome V. p. 351.

† Zeitschrift des deutschen Alpenvereins, Jahrgang 1873, Band IV. pp. 67-78, Die bayerischen Seen und die alten Moränen, Eine Erläuterung zur Karte: "Ideale Uebersicht von Südostbayern zur Eiszeit."

‡ This is in striking contrast with the facts on the south side of the Italian Alps, where the terminal moraines are represented with perfect distinctness on the official topographical maps of the region.

fied, and this material forms as a whole fan-shaped detrital piles at the points where the various streams debouch from the mountain valleys. The contrast between these deposits and those left along the flanks of a range by undoubted glaciers, as, for instance, at the base of the Sawatch Range, in the Rocky Mountains,* is most striking. In the latter case we have great accumulations of almost exclusively angular débris heaped up in two well-marked parallel lines along the sides of the now much diminished streams, and at right-angles to the trend of the range; at the base of the Bavarian Alps, on the other hand, we find water-worn detrital materials forming a belt of irregular width along the whole extent of the range, but spreading to considerably farther towards the north and occupying a fan-shaped area in front of the mouths of the gorges from which the principal streams now issue. Moreover, these deposits of rounded gravel are generally quite distinctly stratified; and if they are of morainic origin their whole mass must have been entirely worked over and rearranged by water after having been deposited by the glacier.

The views of Stark are on the whole adopted and supported by Zittel, who, however, does not hesitate to call to aid a pre-glacial period of floods in order to account for what he calls the "stratified diluvial gravel" [geschichtetes Diluvialgeröll]. He says: "I consider it proved that, over the Bavarian high plateau [Hochebene], the Glacial epoch was preceded by a period of violent overflow or deluges [heftige Überfluthungen], during which enormous masses of detrital material filled up the depressions in the Tertiary land, in which valleys had been previously eroded, so that a level base [Untergrund] was prepared on which the glaciers which were to come later might rest."† Thus, as we perceive, Zittel does, in fact, recognize the necessity of admitting that there was a time in geological history when the precipitation was much larger than it now is. This more copious rain-fall he seems, however, to wish to limit to a certain comparatively brief period previous to the Glacial epoch; while so many other geologists, especially in this country,‡ look upon this time when water was a much more active geological agent than it now is as a phase following instead of preceding the epoch of the greatest ice extension. The subject of the extension of the ice sheet on the north slope of the Bavarian Alps has been insisted on, in the

* See *ante*, pp. 64, 65.

† See Zittel, in Sitzungsberichte der math.-phys. Classe der k. b. Akademie der Wissenschaften zu München, 1874, p. 282.

‡ See *ante*, pp. 184–193.

present connection, at some length, because it seemed to furnish a good instance of the propensity of enthusiastic glacialists to exaggerate the limits of the ice masses, not only in the Alps but in other formerly glaciated regions.*

Extensive observations in every part of the Alps, as well as the examination of much that has been published in regard to the glacial geology of that region, has led the writer to infer that during the period of the greatest development of the glaciers in that range, its eastern portion was less extensively glaciated than the western. This would be in accordance with what we see at the present time, the glaciers of Bavaria and Tyrol being very inferior in magnitude to those of Switzerland. But the geological observer cannot fail to be impressed with the proofs everywhere furnished in the Eastern Alps of the former much greater volume of the streams occupying the valleys.

The question of the position of the line indicating the extreme limits reached by the grand glacier which found its way down the valley of the Rhone is also one not entirely settled. That, in general, the Jura acted as a barrier to its farther progress, and that this range was invaded by the ice to but a slight extent, is clearly shown by the position of the morainic débris along its southeastern slopes. Following down the river Rhone, according to the minute and laborious investigations of Messrs. Falsan and Chantre,† the ice flow made its way for a distance of 460 kilometers (285 miles) from its head on the flanks of the Galenstock, combining with many smaller glaciers coming down the valleys on the northwestern slope of the Dauphiny Alps, and ending on the hills near Lyons, opposite the mass of Mont d'Or, and on the plateau of the Dombes. The thickness of the ice is thought to have been from 1,200 to 1,680 meters in its upper portion; at its lower end it had thinned down to less than fifty.

* Zittel adduces as an argument in favor of the glacial origin of the supposed morainic matter in the region described above, that there are boulders found in it which could hardly have reached their present position without the aid of ice. He admits, however, that similar difficulties present themselves in connection with the older "diluvium," which he himself does not believe to be of glacial origin, and of which he remarks "that the presence in it of large quantities of rolled fragments of crystalline rocks belonging to the Central Alps presents a problem which has not yet been satisfactorily solved." The present writer believes that the solution is not rendered any less difficult by invoking the aid of glaciers. If the presence of boulders in a region where they do not belong can only be accounted for in that way, it will be necessary to extend the ice sheet as far north as Holland, and to admit that it advanced both from the northeast and from the southwest. (See farther on p. 369.)

† Monographie Géologique des Anciens Glaciers et du Terrain Erratique de la Partie Moyenne du Bassin du Rhone, 2 volumes, Lyons, 1880.

In regard to the evidence on which is based the assumption that the ice flow of the Rhone Valley reached as far as Lyons, it may be said that it is not entirely satisfactory. If it is not positively stated by Messrs. Falsan and Chantre that detrital material cannot be moved at all without the aid of ice, that assumption seems tacitly to form the basis of their work. Every boulder and every somewhat peculiar deposit of fine or coarse material is unhesitatingly set down as a part of a moraine, or as in some way the result of glacial action. In short, we have here something of the same difficulty which presents itself at the other extremity of the Alpine chain.*

The former glaciation of the Pyrenees, as compared with that of the present day, appears to have been on about the same scale of magnitude as in the Caucasus. As in the last-named chain, so in the more western one, the ancient ice masses seem to have had much the most extensive development on the northern side of the range. The most important glacier, according to Martins,† was that which, heading in the "cirques" of Gavarnie and Troumouse, descended towards Luz, and being joined by other smaller ones, made its way through the broad valley of Argelez as far as Lourdes. No other of the Pyrenean glaciers advanced so near to the base of the range as this.

The proofs of the former presence of glaciers in the chain of the Vosges, as indicated by Hogard and Collomb,‡ are clear and indisputable. The largest one seems to have been that occupying the valley of the Thur, and terminating at Wesserling, near St. Amarin, where well-marked moraines are to be seen. The length of this ice flow, as mapped by Collomb, appears to have been about eight miles, and several smaller tributaries united with it, especially from the western side. The moraines at the head of the Moselle also, as described and figured by Hogard, are very characteristic.

* M. Tardy, a French geologist, denies some of the conclusions of Messrs. Falsan and Chantre, basing his unwillingness to accept their statements as to the former presence of ice over certain areas on the fact that no striæ have been found there. He himself being an advocate of the existence of Pliocene glaciers, a theory which does not meet the views of Messrs. Falsan and Chantre, they proceed to demolish him in this wise: "D'ailleurs lorsqu'il s'agit de glaciers pliocènes dont l'existence ne nous est pas prouvée jusqu'à présent, il [M. Tardy] se montre moins exigeant. Il n'a pas trouvé de stries sur les galets, les petits blocs des prétendues moraines pliocènes de Varambon et des environs de Belley, mais il n'en poursuit pas moins son idée; les stries alors lui importent peu; *il veut des glaciers pliocènes et il en voit partout,* même lorsque les galets ne sont pas striés" (l. c. Tome II. p. 386). In the opinion of the present writer the same statement will apply to many advocates of the existence of a Quaternary Universal Glacial epoch, "*they must have glaciers and they see them everywhere.*"

† See a series of articles entitled, "Les Glaciers Actuels et la Période Glaciaire," in the Revue des Deux Mondes, 1867, Seconde Période, Tome LXVII. pp. 407–432, 588–615, and Tome LXVIII. 189–223.

‡ H. Hogard, Coup d'Œil sur le Terrain Erratique des Vosges, Epinal, 1851; and E. Collomb, Preuves de l'Existence d'Anciens Glaciers dans les Vallées des Vosges, Paris, 1847.

Having thus briefly indicated the extent of Alpine glaciation at a former period, it will be desirable, before proceeding to discuss the facts presented, with reference to the problem before us, to describe the conditions which prevailed at the same epoch in Northwestern Europe. For this purpose we may begin with the Scandinavian Peninsula, which was the undoubted centre from which the ice masses advanced over a part of Russia and, as is generally believed, over Denmark and Northern Germany. In describing the glacial geology of that region the publications of the Swedish Geological Survey will be the authority chiefly followed, a work most thoroughly and satisfactorily executed.*

The first fact to be noticed in regard to the glaciation of the Scandinavian Peninsula is this: that the striation, which is usually very well marked, is on the whole decidedly radial from the axis of the range. This is easily seen to be the case on consulting the maps of the Swedish Survey,† and not only in Sweden and Norway, but also in that part of Russia which lies between the Gulf of Finland and the White Sea, especially in Finland. This being a well-established fact, we are furnished with a most valuable starting-point, from which all the phenomena of the distribution of the detritus on the surface, whether as effected directly by the glacial masses themselves, or by subsequent aqueous action on previously existing morainic material, may be satisfactorily studied.

The Swedish geologists seem to have established the following sequence of events on the Scandinavian Peninsula. At the beginning of the Glacial period in that region the topographical conditions were quite different from what they are at the present time. A large part of what is now the Baltic Sea was probably land, while the Gulf of Bothnia communicated with the Arctic Sea. The land now forming the Peninsula was connected on the south with the continental mass of Europe. During the period of glaciation the country was covered with ice, with the exception of the highest summits

* See, especially, Exposé des Formations Quaternaires de la Suède, Stockholm, 1868, with an Atlas of 14 maps, this being a *résumé* of the work in the department of glacial geology, by A. Erdmann, late Director of the Survey. A considerable number of smaller papers on glacial subjects has been issued by the Survey since the publication of Erdmann's larger work, in some of which views not entirely in harmony with those of the late Director are maintained; this is especially the case with reference to the much vexed question of the origin of the åsar. The present writer also spent a considerable part of a summer in examining the detrital formations of Sweden and Finland, and has quite recently had an opportunity of seeing something of the surface geology of Northern Germany and Denmark.

† See Map No. 3 of the Atlas to Erdmann's work cited above. Also various Norwegian publications, especially Hörbye's map showing the direction of the striæ in Southern Norway.

and ranges. This was also, in fact, the epoch of striation, of moraine formation, and, to some extent, of boulder transportation. During that time the morainic detritus was more or less worked over and rearranged by the glacial streams.* The land was more elevated than it now is.

This first period of high land and great glacier expansion was succeeded by one in which the country was depressed, although not regularly and uniformly, areas not far distant from each other being sometimes in this respect very differently affected. The region of maximum depression was in the latitude of Stockholm, where it was certainly as much as one or two thousand feet; farther south it was considerably less than that. The ocean gradually submerging the land, the ice fields diminished in size, shrinking constantly. This was the period during which the old morainic deposits were worked over by the sea, the result being their taking the form of long lines of rolled boulders and pebbles, known in Sweden by the name of åsar.

During this process the finer clayey materials were washed out from the coarser and deposited at some distance in a stratified condition. In the clay beds thus formed the remains of marine organisms were buried, thus proving, beyond possibility of doubt, the former presence of the ocean, and the oscillations of the land. This was also the time when icebergs were detached from the glaciers which reached the sea, and by their means a farther transportation of boulders was effected. The glaciers, however, gradually diminished in size as the land sank, and at length came to occupy only the very highest portions of the range. At this time the land became finally so much depressed that a communication was opened across the Peninsula between the seas on each side, a considerable portion of the higher plateaux becoming submerged.

This period of depression of the land was followed by one of elevation — the Post-glacial, namely — which rising continued until the Peninsula attained nearly its present topography. At this time the plateau between Lakes Wenner and Wetter was raised above the water, and became connected with the higher land to the north and south, thus isolating the Baltic Sea, and converting it into a closed basin, its fauna from that time forward gradually losing its Arctic character. Lakes Wenner and Wetter also were no longer connected with the Polar Sea. That they were formerly thus united, however, is proved by the presence in them of a depauperated Arctic fauna.

* The number and volume of these in an extensively glaciated northern region has already been noted in describing the conditions prevailing in Greenland.

Thus, then, according to the elaborate investigations of the Swedish Survey, that region has passed through a cycle of geological phenomena of a somewhat complicated character, but in regard to the general order of which there can be no doubt. We have, first, a period of glaciation, when the land was higher than it now is and largely covered with ice, which made its way down the declivities, striating and polishing the rocks, carrying detritus to lower levels, and, with the aid of the torrents of water melted from the glacial masses during the long northern summer, depositing it irregularly over the surface.

To this first period succeeded an epoch of depression of the land, accompanied by a general shrinking of the ice fields. As the surface by its sinking was brought into a position to be acted on by the sea, the detrital material previously irregularly scattered over it as left by the ice sheet was worked over and rearranged, the finer clayey portions being carried off and deposited in a stratified form at some distance, the coarser left on the shore forming long lines of water-worn boulders or åsar. At this time icebergs were also doing their share of the work in transporting detrital materials to greater or less distances, depositing a portion of them over Central Russia and Northern Germany.

The third epoch was that in which the Scandinavian land mass rose again from the water, gradually assuming the outline which it now has, the Baltic Sea becoming closed on the north, while a narrow passage connected it on the south with the German Ocean. During this period the various previously existing detrital deposits received farther modifications, such as would necessarily result from the action of the ocean waves and currents on loose materials lying upon a sloping surface and gradually brought by the rising of the land into such a position as to be subjected to their influence. Moreover, as a larger area became lifted above the water the size of the rivers increased accordingly, and fluviatile action became more and more conspicuous, exercising an important effect in modifying the form of the previously existing detrital deposits. Thus, by degrees, the surface of the land attained its present condition, with its great variety of gravel and clay deposits, the former being collected in considerable part in the form of ridges parallel with the coast line, while the latter are widely spread over the surface, especially in the southeastern portion of the Peninsula, whence they have been distributed in part through the river valleys by subsequent fluviatile action.

When we endeavor to follow the course of events during the Glacial period beyond the borders of Scandinavia itself, and especially to ascertain how far the ice sheet which originated on the mountains of that country made its way in the direction of Russia or Germany, we meet with the same difficulties which have already presented themselves in connection with Alpine glacial geology. In Northern Europe, however, we have an additional complication in the undoubted presence of the sea over a portion of the region and during a part of the time. This enables us to appeal to icebergs for assistance in conveying the detrital material to a distance from the place of its origin. As it is only within a few years that the nature and distribution of the erratics of Russia and North Germany have begun to be studied with care, it need not excite wonder that the facts have not yet been clearly made out. Indeed, a more complicated condition of things than might perhaps have been expected has revealed itself, and it seems as if with all the assistance which can be invoked from glaciers, icebergs, and fluviatile currents, there were still phenomena in connection with the distribution of the erratics over Western and Northern Europe for which no reasonable explanation could be offered. However much opinion may differ on other points, it will be no longer maintained by any one that the detrital material in question was brought from the north — either wholly, or in large part — by the aid of a Polar ice-cap; the direction of the striæ in Northwestern Russia and the distribution of the erratics themselves are equally opposed to that hypothesis.

With regard to the probable extent of the Scandinavian ice sheet and the causes of the distribution of boulders over Russia, the opinions of observers are far from unanimous. The older geologists, almost without exception, favored propulsion of the boulders by great waves or powerful ocean currents rather than transportation by ice. Murchison thought that the elevation of the Kola Range might have produced a wave of translation by which boulders would be carried in all directions from the centre of disturbance, and to great distances.* Similar views had been previously maintained by Sefström and Böhtlingk.† Nordenskjöld brought in the agency of ground ice carried south from the Polar Ocean by winds and currents.

Grewingk, who made a careful geological examination of the region bordering the Gulf of Finland on the south, also rejects the idea of an ice sheet

* See Geology of Russia in Europe and the Ural Mountains, London, 1845, Vol. I. p. 534.

† Bulletin Scientifique publié par l'Académie Impériale des Sciences de St. Pétersbourg, Tome VII. 1840, 107–128, and 191–207. Bericht einer Reise durch Finland und Lappland.

extending over that region, for the reason that the country is not suited to the development of glaciers, and because, also, there are no detrital accumulations in that region which can be likened to moraines. He shows how, in many places along the shores of the Gulf, striated surfaces are formed at the present day by stranded ice. Hence he concludes that the hypothesis of a continuous ice sheet over the Baltic provinces need not be adopted, since the facts can all be accounted for without the necessity of invoking the aid of phenomena for which we find no parallel in what is now taking place.*

Fr. Schmidt, who has also occupied himself extensively with the glacial phenomena of the Baltic provinces, is also inclined to consider that there is great probability that much of the striation and transportation of the boulders in that region was done by icebergs. The reasons he gives for this are, the great inequality in the character of the striæ, and their variation in direction according to local topographical conditions. He also remarks that he has had abundant opportunity to observe the striating and polishing effected at the present time by floating ice masses on the rocks in the lower part of the valley of the Yenisei.†

Helmersen, on the other hand, to whose elaborate work on the boulders and detrital deposits of Russia reference has already been made,‡ concludes that "at the close of the Tertiary epoch Finland and Northwestern Russia, contemporaneously with Scandinavia, were covered with an immense ice sheet [mächtige Eisdecke], which, like the present glaciers, had an outward motion, that is, from a central region towards its borders."§ It is not easy to make out, however, whether Helmersen considers this ice sheet to have been continuous with that originating in Scandinavia, or an independent one moving from the mountains of Finland as a centre. If the direction of the striation is correctly represented on the map published by the Swedish Survey, there can be little doubt that, if there was a continuous glacial mass

* Geologie von Liv- und Kurland, mit Inbegriff einiger angrenzenden Gebiete, Aus dem Archiv für die Naturkunde Liv-, Est, und Kurlands, Erster Serie, Band II. (pag. 479–774) besonders abgedruckt, Dorpat, 1861, p. 103.

† See Bulletin de l'Académie Impériale de St. Pétersbourg, Tome VIII. 1865, pp. 339–368, also a later article on the Glacial and Postglacial formations of Esthonia and Sweden, quoted in full in Helmersen's Studien über die Wanderblöcke, 1869, pp. 55–59. The author in this later article inclines more strongly than in the first one to adopt the theory of transportation and striation by icebergs, in preference to that of a general ice sheet coming from the Scandinavian Range. He also calls attention to the fact that in a part of Sweden (Gothland) the very well marked striæ run parallel with the coast, and do not radiate from the axis of the range.

‡ See *ante*, p. 351.

§ l. c., p. 124.

extending over Finland, it came from the Scandinavian Range. The mountains occupying the Kola Peninsula would appear to have been heavily glaciated also; but the direction of the striæ, so far as known, does not indicate that to be the region from which moved the ice sheet by which Finland was covered.

It is a little curious that the different writers on the glacial geology of Northwestern Russia differ so much in opinion in regard to the important point of the constancy in the direction of the striæ. More minute investigations in that country seem to be much needed. Beyond the limits of the striated region there is a wide belt over which gravel and boulders are more or less irregularly scattered, extending almost as far south as the parallel of 51°.* That this transportation of detrital material over the southern and southeastern portion of the "drift region," and beyond the area of striation, was largely effected by icebergs seems to be admitted by all or nearly all those who have written on the glacial geology of Russia. Yet the fact that marine remains have not been found in these deposits is a stumbling-block in the way of the acceptance of this theory, although it does not render any other more plausible. We have only to say, with Helmersen, "that they may yet be found, since our [the Russian] diluvium has been so little investigated."

How far into Russia did the ice sheet originating in the Scandinavian mountains extend? How much of the distribution of the boulders, and of the detritus generally, was done by water, and how much by ice? What was the relative importance of the work of glaciers and icebergs? These are the questions which the Russian geologists have found it so difficult to answer. And similar questions raise similar difficulties as asked with reference to North Germany, Holland, and even the British Islands. Over all the region to the south and southwest of the Scandinavian glacial centre various marks of the former presence of ice are met with, complicated with abundant indications of the work of water. The delineation of the exact line at which the moving ice sheet stopped, when at its greatest extension, has not yet been so satisfactorily accomplished as to command the assent of all geologists. Indeed the phenomena are extremely perplexing, and although

* The southern and southeastern "limit of northern boulders" is marked in Murchison's map (in "Russia and the Ural Mountains") as having its most southern point near Voroneje, in latitude 51°; thence it trends to the northeast, and just before reaching the Ural, in latitude 62°, bends sharply back to the northwest and meets the coast of the Arctic Sea only a little to the east of the Kola Peninsula.

it is almost a century since Wrede promulgated the idea that the boulders of Northern Germany had been brought there by icebergs,* it is only within a few years that geologists have begun to make minute explorations in regard to the position of the localities from which the materials in question have been brought.

The diluvium — the name by which the superficial detrital materials, not alluvial, are generally called by the German geologists — of North Germany is always well water-worn. It consists of sand, gravel, marl, marly clay — in short, of rolled fragmental and comminuted material of all sizes. In some localities there are even beds of imperfect coal [Braunkohle] enclosed in it. Much of this material is stratified; in some cases it is very irregularly heaped together.

To the east of the Weser this detritus is largely of northern origin; west of that river this is much less the case, and as we go south on the great German plain, we find more and more material of southern origin mixed with it. Between the Saal and the Oder southern detritus is largely intermingled with that of northern origin, and in places exceeds it in quantity. Near Leipsic the gravel is chiefly made up of southern materials.† But to give even the briefest abstract of what has been done in this line of investigation would require more space than is here at the writer's command.

As a specimen, however, of what is doing towards a solution of some of the problems connected with the origin and distribution of the superficial detritus of this region, the investigations of Professor Martin of Leyden may be mentioned, and some of his principal results cited. This geologist has examined with care the erratics of Holland, and particularly those of sedimentary fossiliferous rock, for the purpose of referring them so far as possible to the region from which they were brought. It is a curious fact that these deposits of foreign boulders, all of which are thoroughly rolled and water-worn, are not spread rather uniformly over the country, as is chiefly the case to the east of the Elbe, but collected in certain localities in large quantity [an einzelnen Punkten in grossen Mengen aufgehaüft], while the intervening ground is almost entirely free from them. These rolled rock-fragments represent various geological formations. Those of Silurian age are predominant, and are found on examination to have come from the Baltic Provinces,

* In Geologische Resultate aus Beobachtungen über einen Theil der Südbaltischen Länder, Berlin, 1794.

† These statements are chiefly on the authority of Jentzsch in Schriften der phys.-œkonom. Gesellschaft zu Königsberg, 1877, p. 228, and Dathe in Neues Jahrbuch für Mineralogie, 1877, p. 165.

and especially from Esthonia. The material derived from geological formations more recent than the Silurian seems to have come almost entirely from the mountains of Northwest Germany and from the Eifel. The most probable mode of transportation, according to Professor Martin, was by icebergs; by this supposition, at least, some of the theoretical difficulties are removed which apparently could not be under any other hypothesis. He closes, however, with the remark that "it is evident that in reference to our drift there is a sufficiency of unanswered questions [genug ungelöster Fragen]."*

In view of the large body of facts collected by the German geologists, it seems necessary to admit the actual presence of ice — over portions of the region, at least. Professor Credner, Chief of the Geological Survey of Saxony, considers the evidence as decisive in favor of the former extension of the Scandinavian ice sheet as far south in Saxony as the vicinity of Chemnitz, a little south of the parallel of 51°. This opinion is based on the occurrence of striated rocks at several localities,† and also on the character of the detrital material on the surface.‡ The writer has examined in the Museum at Leipsic the specimens of striated rocks collected by the Saxony Survey, and while admitting that they are the work of ice, does not consider it as proved that this ice was not in the form of floating bergs or fields detached from a distant fixed sheet. The difficulties in the way of the adoption of any theory of the occurrence and distribution of the detrital materials in this region are very considerable, as may be inferred from the fact that Credner has to admit that the glacial sheet moved up hill and in a direction just the opposite of that in which the streams of the region were flowing at the same time.§ Nor is the writer able to reconcile the statements made by the different geologists who have published in regard to the surface geology of North Germany. No one has had so much to do with the examination of the "diluvium" of that region as Dr. A. Jentzsch. He expresses himself in regard to the striated surface of the Muschelkalk at Rüdersdorf, considered by some of the Swedish

* Niederländische und Nordwestdeutsche Sedimentärgeschiebe, ihre Übereinstimmung, gemeinschaftliche Herkunft, und Petrefacten. Leiden, 1878, p. 59.

† At Klein Steinberg and Taucha, near Leipsic; at Landsberg, near Halle a/s; and Lommatzsch, near Meissen.

‡ See Credner, Über Glacialerscheinungen in Sachsen, in Zeitschrift der deutschen geologischen Gesellschaft, 1880, Band XXXII. pp. 572–595; also, Über die Vergletscherung Norddeutschlands während der Eiszeit, Verhandlungen der Gesellschaft für Erdkunde zu Berlin, 1880, No. 8.

§ "The surface of Northwestern Saxony rises gently towards the southeast; the rivers therefore flow in general in a northwesterly and northerly direction, and this *was the case already during the Glacial epoch*. . . . . The transportation of the native as well as of the Scandinavian material of the Northern ground moraine took place therefore in a direction opposite to that of the general direction of the streams." l. c., p. 577. The reader will notice the portion of the above statement italicized by the present writer.

and German geologists as the work of glaciers, as follows: "The very numerous reasons which lead me to ascribe those striated surfaces [at Rüdersdorf] to the action of floating ice and not of glaciers, I intend to bring together in a special article."* In view of the discrepancies of opinion which are seen to prevail among those who have devoted so much time to field work in Northern Germany, it appears that at present it is not possible to draw a line on the map marking the limits of the Scandinavian ice-sheet on the south, any more than this can be done on the southeast and east.†

Similar conditions of uncertainty meet us when endeavoring to connect the Scandinavian ice sheet with the glaciation of the northern portion of the British Islands; but the larger number of the most recent observers seem to consider it proved that the glacial covering of Scandinavia did extend so far as to meet and unite with one descending from the Scottish Highlands. In the words of Messrs. Peach and Horne, assistants on the Geological Survey of Scotland: "The results of our previous observations in Shetland and Orkney which have appeared in the *Quarterly Journal of the Geological Society* (Vol. XXXV, p. 778, and XXXVI, p. 648) point to the conclusion that during the climax of the Ice Age the Scandinavian and Scotch ice-sheets coalesced on the floor of the North Sea, and that a great portion of this ice-field moved in a north-west direction towards the Atlantic."‡

Furthermore, it is also generally admitted that over considerable portions of Scotland, Wales, and Ireland local glaciers moved from the higher regions towards the lower, striating and polishing the rocks over which they passed, and doing all the ordinary work of ice.§ The evidence as to the local glaciation is decidedly more complete and convincing than that by which the view of the confluence of the Scotch and Scandinavian ice sheets is supported.

The entire area covered by ice, accepting the hypothesis that the sheet

* Schriften der phys.-œkonom. Gesellschaft zu Königsberg, Band XVIII. 1877, p. 229.

† Those who wish to have a vivid idea of the complexity of the phenomena in question are invited to read pp. 92 and 93 of Professor Credner's article "Über Schichtenstörungen im Untergrund des Geschiebelehmes, an Beispielen aus dem nordwestlichen Sachsen und angrenzenden Landstrichen," in the Zeitschrift der deutschen geologischen Gesellschaft, Band XXXII. 1880. From a short notice in Petermann's Mittheilungen, 1882, p. 273, of a recent paper by Dathe (not yet received by the present writer) it appears that he now places the southern limit of the glaciated region of North Germany along the line indicated by the following localities: the Mittelgebirge, the Sudeten, the Riesengebirge, the Erzgebirge, the Franken Wald, and the Thüringer Wald. (These mountain ranges are nearly on the line of the 51st parallel.) The original paper is published in the Jahrbuch der k. preussischen geologischen Landesanstalt for 1881, pp. 317–330.

‡ Proc. Royal Physical Society of Edinburgh, Vol. VI. 1881, p. 316.

§ See, for Ireland, Hull's Physical Geography and Geology of Ireland, London, 1878, p. 211; and for the British Isles generally, J. Geikie's Great Ice Age, London, 1874, and Second Edition, 1877 (*passim*).

reached to Scotland on the west, covered Finland on the east, and extended to Dresden on the south, would be not less than half a million square miles. But this is so large as to entirely dwarf the glaciated region of the Alps, so that the latter must be admitted to hold a quite subordinate position as compared with the part played by the Scandinavian Ranges during the time of the greatest ice extension. In fact, the most reasonable view to take of the glaciation of Western Europe is that it was one phenomenon, all the higher portions being more or less glaciated in sympathy with the existence of a mass of ice on the extreme northwest of the continent covering an area of half a million square miles.

Many of the interesting topics which are suggested by the brief description of the areas of past and present glaciation given in the preceding pages must be left unconsidered. All that concerns us particularly at present, or, at least, all for which space can here be found, is the answering of the question whether the facts presented oblige us to admit that the mean temperature of the earth must have been lower than it now is at the time when an ice sheet covered Scandinavia and extended for an indefinite distance over the adjacent continental mass of Europe.

The first point which may be made in this connection is, that the cause of the phenomena in question must be sought for in changed local conditions, and not general ones or such as must necessarily affect the entire surface of the earth, or of one hemisphere even. The fact that the Ural Mountains were not covered with ice, or even glaciated in the slightest degree, while the Scandinavian Range was the centre from which an immense ice sheet extended itself, has an important bearing on the question before us. The absence of traces of a former glaciation in the Ural seems more remarkable, as contrasted with the condition of the Scandinavian Mountains, when we consider that these two chains are at no great distance from each other, that they have about the same position in latitude, nearly the same direction, and that they do not differ very greatly in altitude. In connection with the absence of any marks of a Glacial epoch in the Ural, we have also to take into consideration the fact that the Altai Range presents us with conditions of an analogous kind, although the last-named chain lies in a somewhat more southern latitude.

We are furnished with a good opportunity for comparing the conditions requisite for more or less extensive glaciation in three regions which in several important respects closely resemble each other, but which are, and have been, very differently situated as regards their being covered with ice or snow. The regions in question are, the Ural Mountains, the Scandinavian Range, and the West Coast of Greenland. The latter is, in reality, a mountain range, as has been shown in the preceding pages,* although we unfortunately know neither its elevation, nor how complicated its structure may be, nor how far it extends to the east. The important point in connection with our present inquiry is, that these ranges of mountains occupy similar positions as to latitude. They all lie between the parallels of 60° and 70°. It is true that Greenland extends far to the north of 70°, and also that the Ural Mountains are prolonged considerably to the south of 60°; yet, as that part of the former country which lies between 60° and 70° is as heavily glaciated as any portion of it, and as the Ural presents the same characters to the south of 60° as it does to the north of that parallel, we may, for purposes of comparison in connection with our present inquiry, fairly consider the three ranges as being similarly situated in latitude.

Yet these chains differ entirely from each other as respects their glaciation, both past and present. The Ural is not now, nor has it been at any former time, to any perceptible extent the abode of ice or permanent snow. The Scandinavian Range has at present some large *névé* fields scattered over its summit, from which numerous glaciers descend, but it cannot be said to be glaciated to any considerable extent. That it was so in former times has been shown in the preceding pages. The west coast of Greenland, on the other hand, is in the full enjoyment of a "Glacial epoch," — that is to say, it is in large part covered with ice or snow.† Here, then, we have presented to us an opportunity for investigating the problem of glaciation, and of ascertaining by comparison of topographical and climatic conditions how it is that regions at the same distance from the Pole are so differently conditioned as respects their present glaciation, it being reasonable to suppose that similar differences must have had similar results at a former epoch, and that we may thus have some light thrown on the problem before us.

It is necessary, however, before proceeding farther, to call to mind that even in Greenland we have not all the conditions which were realized in Scandinavia during the culmination of the Glacial epoch in that region.

* See *ante*, pp. 296–310.

† It may be well to call attention, in this connection, to the fact that a part of Iceland is as thoroughly under the *régime* of a Glacial epoch as any country can be, while another and a lower portion is inhabited by an enlightened people, and cultivated to a certain extent.

There is no confluent sheet of ice at the base of the mountains, spreading over the comparatively level region, and extending to a great distance from the place of its origin. We do not even know positively that it has been so at any former time. The evidence as to former glaciation of parts of Greenland now free from ice is so conflicting that no positive statement in regard to it can be made. Still, the weight of the testimony is to the effect that the glaciers are — in places, at least — smaller now than they have been: whether essentially so cannot be stated. If, however, we could indicate the changes of climate or topography which would bring about in the Scandinavian Range a condition similar to that of Greenland at the present time, no doubt the larger number of geologists would feel that, if the problem had not been entirely solved, considerable progress had been made towards its solution.

The first thing which impresses us, in comparing the three regions in question, is the fact that the least glaciated is that one which has a position indicating for it the most continental climate, while the one which is most covered with snow and ice is so isolated from other land as to give a marked oceanic character to its climate. The Ural Mountains extend through the great land mass of Eurasia: the mean annual precipitation over the adjacent level country on both sides the range is very small, ranging from sixteen to twenty inches only; and even on the summit it is not much larger. On the Scandinavian Range, on the other hand, the precipitation is large, and especially on the western side, although we find it rapidly falling off when we cross the water-shed and descend upon the Swedish plains. Of the amount of the snow-fall over the higher portion of Greenland — the *névé* region from which the glaciers are supplied — we have, of course, no statistics, but we know that it must be large, unless we are disposed to believe, with Bessels, that the icebergs which are now being formed owe their existence to a stock of snow laid up in former ages, when the precipitation was much greater than it now is.*

Again, the least glaciated range is the one topographically least fitted for the development of extensive glaciers. These, as has been shown in the preceding pages, can only originate where the form of the surface is such as to favor the delivery of the frozen precipitation of a large area at one point. Thus, as we have seen, the *névé* fields of Norway are like great permanent reservoirs, the overflow from which takes place through the notches or gaps

* Die Amerikanische Nordpol-Expedition, p. 471.

in its edge. Where these are deeply cut so as to strike the *névé* mass at considerable depth, there the outflow, in the form of a glacier, is proportionally large, and reaches far down the slope of the range. The same is the case on the west coast of Greenland, except that there the topographical conditions seem to be still more favorable than they are in Scandinavia. It is true that our knowledge of the interior of Greenland is very imperfect, but a comparison of all the facts observed there leads us to infer that the form of the surface is particularly well fitted to give rise to extensive ice masses.

The Ural Mountains, on the other hand, offer the least favorable conditions possible for the accumulation of snow. The chain is narrow and simple in structure, as already pointed out. It is also somewhat less elevated than the Scandinavian Range, while the latter is in all probability much inferior in height to the mountains on the west coast of Greenland.

If, then, we wished to reproduce in Scandinavia the conditions which would bring about a recurrence of its former much more extensive glaciation, we should, as we are led to infer from an examination of the present situation of Greenland, have to raise the height of the range, give it still more of a plateau character than it now has, and isolate it, as much as possible, from other land masses. But this appears, according to the investigations of the Swedish geologists, to have been the condition of the country during the time of its former glaciation. The Scandinavian Range had at that time a greater elevation than it now has, and there can be little doubt that a large part of Northern Germany and Northwestern Russia was under water at least during a considerable portion of the Glacial epoch.

Thus we have shown that precisely those conditions existed in Scandinavia at the time of the largest development of snow and ice in that region which a comparison of its present topography and climate with that of the not far distant Greenland seemed to suggest as likely to bring about the extensive glaciation which is now exhibited in that country. That there were other favorable circumstances prevailing at that time in Northwestern Europe is highly probable; but it would be impossible, in the present condition of our knowledge of the climatology of the Polar regions, to say exactly what these conditions are. It is very possible that when we know more of the nature of the Polar winds and the causes of the peculiar distribution of precipitation on the lands lying within the Arctic Circle, we shall be furnished with data which will enable us to go still farther into details in regard to what change in the position of the land masses, and consequently in that of the ocean currents, would help bring on an abnormal extension of ice and snow in the Scandinavian Peninsula. That a much greater precipitation than that now taking place would be one of the requisites for more extensive glaciation of the region in question can hardly be doubted. This desired increase would be the necessary result of a higher mean temperature of the earth. The greater the actual amount of moisture raised from the surface of the ocean by evaporation, the larger would be the precipitation as a whole; and local conditions would cause this to be very unequally distributed, just as they now do, the result being that in certain regions the fall of rain or snow would be far superior in amount to what it is at the present time.

Finally, we may turn to the consideration of the phenomena exhibited in the second great and important region of past glaciation to which reference has been made when indicating those parts of the earth where ice and snow have once played a more important part than they now do. Complicated as are the conditions over the glaciated region of which the Scandinavian Range is the centre, we find them considerably more so in Northeastern North America. The present volume will not, however, afford us the necessary space for anything like a complete analysis of that which has been published on this side of the Atlantic, bearing on the nature and origin of the Glacial epoch, including, as this material does, everything connected with the occurrence of the superficial detrital formations over an area of more than a million of square miles. All that can here be done is to point out some of the more important facts having a special bearing on the question before us, discussing them only to such an extent as is necessary to enable the reader to form an idea of what is known, or may be reasonably inferred, with regard to the climatic conditions connecting themselves with the epoch of the former greater extension of ice in Northeastern America, and to satisfy himself especially that this phase of our geological history was not the result of a lowering of the mean temperature of the continent.

In order to enter understandingly into the contemplated discussion it will be necessary to present a brief statement of the facts with which we have to deal. This, however, will not be an easy matter, because, these being often obscure, as has already been explained, geologists are wont to interpret them in the light of previously adopted theories, so that on many points the evidence is of a most contradictory kind. In making the following statement the writer will endeavor to present the case impartially, relying on his own examinations, which have extended over a large part of the area in question, and also on a pretty careful perusal of most of that which has been published in this department of geology.

The first important fact to be noticed in the formerly glaciated portion of Northeastern North America, commonly known as the region of Northern Drift, is the occurrence of large amounts of detrital material on the surface which cannot be referred to the place of its origin in the same easy way in which similar materials can be over the region of the Cordilleras, where it is evident that the sand, gravel, and boulders have been carried down the slopes of the adjacent mountain ranges by gravity, aided by currents of water, in a manner which is natural, and in entire harmony with the existing topography. In the Northern Drift region, on the other hand, such a connection between the form of the surface and the movement of the detrital masses appears, at first sight, to be altogether wanting, and certainly is, in many places, very obscure.

Here the marked difference in the topographical features of the two sides of the continent is forced upon our notice. The western side is traversed by numerous high chains of mountains, which give strong outlines to the profiles of its surface. The eastern region, on the other hand, has few well-defined ranges, and these only of moderate height. Much of the so-called Northern Drift region is very nearly level, having an elevation of not more than from 500 to 1,000 feet. Another large area is a plateau of moderate height, ranging between 1,000 and 2,000 feet above the sea-level. Within the borders of the United States there is nowhere, west of the Adirondacks, within the limits of the Drift region, anything which can be called a mountain range, until we reach the southwestern part of Lake Superior, where the trappean rocks form a chain of hills, hardly anywhere, however, so much as a thousand feet above the level of the lake.

Still more perplexing is the fact that in the centre or axis of the Drift region, where the peculiar phenomena of the Glacial epoch are most characteristically displayed, there is an area of exceptional depression, a large portion of which is below the sea-level, this and many thousand square miles in addition being now covered by water. This is the more remarkable, because this is the region toward which the striæ, to a certain extent, seem to converge, and where the continental ice sheet must have originated, or over which it must at least have passed, if it ever had an existence. Instead of an elevated mountain range from which the glacial mass descended, as has been seen to be the case in every other part of the world, we have therefore almost exactly the reverse, — a condition of things which greatly enhances the difficulty of getting a generally recognized starting-point from which to proceed to a co-ordination of the drift of this country with the glacial formations of Europe.

Omitting for the present the consideration of the striation in the Northern Drift region, we may examine, first, the nature and distribution of the detrital material, the origin of which has been the object of so much discussion among American geologists during the past forty years. Complicated as are the phenomena by which this material has been brought into its present position, and various as are its lithological aspects, there are certain features of its occurrence which are thoroughly characteristic, and which may be considered, to the exclusion of those local peculiarities which are not of special importance in the present connection.

The Northern Drift of Northeastern America consists, in general, of unconsolidated detrital material lying on the surface, a portion of which detritus is found on examination to have been brought from more northerly regions. The movement has not often been in a precisely meridional direction; but it has, on the whole, been from some more northerly point towards a southerly one. The nature of this transportation is, in general, as follows: Starting from an outcrop of some easily recognized rock, we find that fragments of it have been carried southerly for a considerable distance, and that, as a rule, these fragments grow smaller and become more thoroughly water-worn as we recede from the place of their origin. Taking a mass of detritus at any point, we find, in most cases, that it is largely made up of material similar to that occurring *in situ* close at hand, with a certain admixture of other materials brought from regions farther north, and often from a great distance in that direction.

The character of the deposits commonly included under the general name of drift by American geologists is extremely varied. Over a large part of the eastern portion of the Drift region the predominating material is what may properly be called gravel, made up of fragments of rock of moderate size, and almost invariably thoroughly water-worn. Most of this gravel is more or less distinctly stratified, and with it are associated frequent beds of sand of various degrees of fineness. These intercalated deposits of sand often exhibit cross-stratification in a very marked degree. The lower we descend, and as we approach the level of the streams in the larger valleys, the finer, as a rule, the material becomes. In such positions brick-earths and clays, often very delicately laminated, form a part of the detrital mass, marking the passage of the "diluvial" into the "alluvial" deposits. The sides of the rivers frequently exhibit a greater or less number of terraces, showing that the water once flowed in these valleys in much larger volume than it now does.

As we proceed westward, the character of the geological formations changes, and at the same time that of the overlying detrital materials. The rock in place being mostly sedimentary and non-crystalline, the presence in the drift of hard metamorphic and granitic materials becomes a more striking phenomenon, since the fact that they were brought from a distance is evident to the most superficial observer. With much rolled material of a coarser kind of both local and foreign origin, we find a large and sometimes a predominating quantity of finer detritus, including both clay and the peculiar deposits called by the names of "loess" and "bluff formation." Indeed, the clay which usually forms the lower member of the detrital series becomes an extremely persistent one when we reach the vicinity of Lakes Michigan and Superior.

As a rule, the detrital formations described and included under the term "drift" are most extensively developed in New England and on the southern borders of the Great Lakes. In the former region they extend to the sea without marked change of character; but westward are spread over the land surface, gradually thinning out as we recede from the lakes, and becoming more and more confined to the vicinity of the present rivers or to channels of now obliterated streams. In the great river valleys, on the other hand, the traces of materials of northern origin, becoming finer and finer, may be observed far beyond the region where anything of the kind can be discovered in the adjacent higher lands.

The facts thus stated — in the most general way, as will be admitted — appear at first sight to indicate that the detrital deposits in question are simply the result of the action of water. The predominance of sand and gravel, their occurrence to a large extent in the stratified form, the alternations of coarse and fine materials — these seem to be unquestionable evidences of an aqueous origin.

That the drift should have been borne, on the whole, in a general southerly direction — over a large part of the region, at least — need not excite surprise, when we call to mind the fact that the present drainage of much of the area covered by the drift is to the south. The larger rivers — as the Hudson, Connecticut, and Mississippi — have an almost due south course, and the water-shed on the south side of the Great Lakes is comparatively very near them, so that the general direction of many of the smaller streams is southerly.* Similarly, in Canada, the general course of the streams emptying into the Lakes is southerly, with the exception of the Ottowa, which runs nearly east. If it were not for the existence of the depression occupied by the Great Lakes and a small area to the south of them, we might say that throughout the region of the drift the general course of the streams is to the south. But we have excellent reasons for believing that over a large portion of the area at present occupied by the Great Lakes and drained to the northeast, the water did, during a former and not very remote period, flow towards the Gulf of Mexico.

If, then, we had only to deal with those features of the Northern Drift which have been already pointed out, namely, the existence, over extensive regions, of detrital material, water-worn and more or less distinctly stratified, having largely intermixed with it pebbles and boulders of rocks in place somewhere to the northward, the difficulties to be overcome in solving the problem of the origin of this formation would not be insurmountable. Borne out by a great number of facts, collected all over the world, some of which have been laid before the reader in a previous chapter, we should say that there was everywhere proof in the region in question, as well as in so many others, that precipitation was once much greater than it now is; that the rivers and smaller streams having, over a large part of the Northern Drift area, a general southerly direction, the detrital material abraded from the rocks has been carried southward, just as we have seen that in the Sierra Nevada, during a time of greater rain-fall, vast accumulations of gravel, resembling in many respects those of the Northern Drift region, have been spread out on the flanks of that range.

In taking this view of the phenomena in question, we should — to a certain extent — be doing what was done by the earlier American geologists, heads of the first great Geological Surveys of New York, Pennsylvania, and other States, who were engaged in this work when the Northern Drift began to occupy the attention of observers. They — Jackson, Hitchcock, Emmons, James Hall, Mather, Vanuxem, Rogers, and others — all considered the

* The insignificance of the area, on the south side of the Great Lakes, in which the drainage is towards them is well illustrated by the fact that the number of square miles of territory, in the United States, on the lake side of the water-shed between the Lakes and the Gulf of Mexico is only 175,000, while the area drained into the Gulf of Mexico covers 1,725,000, or nearly ten times as much.

phenomena of the drift to be chiefly due to the agency of currents of water. In one important respect, however, we should differ from these distinguished pioneers of the science in this country, namely, in that the view adopted by them was, almost without exception, to the effect that it was the water of the ocean which did the work. The currents were marine, as they believed, and not fluviatile. The reference of work of this kind to the agency of the ocean was, in the early days of geological inquiry, a thing of almost universal occurrence: at the present time the importance of rivers as agents of geological change is much more generally recognized — that is, by those who do not consider everything the work of ice. In this case, however, there can be no doubt as to the absence of the sea over a large part of the Drift region, during at least a considerable portion of the Glacial period, for not only are marine fossils entirely wanting there, but positive proofs exist of the presence of fresh water, or of land surfaces, in the form of buried vegetation, and remains of land and fresh-water animals.

That the courses and positions of the former rivers cannot be made out with much of any detail is not a matter to excite surprise. Even on the west slope of the Sierra Nevada, a district so much smaller in extent than the great Northern Drift region, with all the help afforded by extensive mining operations, it has often been impossible to reconstruct the former drainage, although its general character could be recognized without difficulty. And if, in spite of the very marked topographical features of the Californian region, there have been many cases in which isolated fragments of old river channels could not be brought into relations with each other, although closely adjacent and similarly situated, how much less likely that this could be done over a country of so varied a character, with such irregular lines of watershed, and with so marked an absence of a dominating range as we find in the Northern Drift region.

No geologist denies the agency of water in the formation and deposition of at least a considerable portion of the drift. The evidence is plain that much of it has been deposited in lacustrine basins; that a large part of the finer materials has resulted from the decomposition or solution of the rock in place, having been moved either not at all or but a short distance from its original position; that almost all the rounding and the arrangement in stratified form has been the work of water.

The question now arises, What are the obstacles to ascribing all the phenomena of the drift to the agency of water? The principal one, no doubt, is the frequent occurrence of striated rock surfaces, such as can only be regarded as the work of ice. Over an extensive area within the region of the Northern Drift such striæ are common; and although they have been the object of constant discussion during the past fifty years, unanimity of opinion has not been attained as to whether they are the work of icebergs, local glaciers, or a continental ice sheet. More and more, however, of later years, geologists have inclined to consider these striated surfaces as having been the result of the movement of one confluent mass of ice which advanced from the north, and once covered the whole region now occupied by the Northern Drift.

This ice sheet was originally considered to have been a part of a general ice-cap, which extended from the Pole in all directions for an indefinite distance, and was regarded as the necessary result of a lowering of the earth's mean temperature. The observations of the last few years have rendered this view of the nature and origin of the ice of the Glacial epoch entirely untenable, as has been abundantly proved in the preceding pages. Most of those who now advocate the former presence of a general ice sheet do not consider themselves bound to indicate whence it came, or under what topographical or climatic conditions it could have originated; it is sufficient for them that the presence of ice seems to be demanded, and it is, in accordance with this necessity, extended over the surface indefinitely, regardless of the topography, the conditions of its existence being left to the climatologist to discover. There are those, however, who still incline to look upon the so-called continental glacier with suspicion, and rely chiefly on icebergs floated from the Arctic regions, to which, in conjunction with local glaciers, they ascribe the striation in question.

There is no doubt that the character of the striæ in the Drift region of Northeastern America is extremely perplexing, lacking, as these do almost entirely, that uniformity of direction and radiation from a central area which we have seen to be of so much assistance in making out the facts in Scandinavia. That topographical conditions greatly resembling those now prevailing in the Drift region have been largely instrumental in governing the direction of the striæ, can hardly be doubted. In the valley of the St. Lawrence, however, and in the vicinity of the Great Lakes generally, the movement of the ice, whether fixed or floating, although parallel with the course of the stream, has been in the opposite direction.

Again, many observers agree in reporting the existence on high ridges and on or near the summits of the mountains, especially in New England, of well-defined striæ which do not run in conformity with the topography, but cross the ranges obliquely, holding approximately the same general southerly direction over a wide area of country, as if made by a body of ice not hampered in its movement by local conditions.

Those who have endeavored to account for the presence of such a glacial covering over so large a part of the country, or to fix the place where it originated and assign a cause for its motion in the direction demanded, have had a difficult task to execute. The geologists who, as already mentioned, have simply appealed to the condition of things in Greenland, as a perfectly satisfactory illustration of the peculiarities of the Glacial epoch in North-eastern America, and as removing all the difficulties which these present, are greatly in error, as must have been made apparent by what has been stated in the preceding pages. There is no motion of the glaciers in the Arctic regions except down hill, and nothing abnormal in the mode of occurrence of either snow or ice.

Some have considered that the ice of Greenland extended down so far as to cover the glaciated region of the Northern Drift. This theory seems not only not in harmony with the direction of the striation and the general topographical character of the intervening region, but to be from every other point of view a climatological impossibility. Others have maintained that the sudden ushering in of a period of intense cold would have caused an immense fall of snow, and that this, becoming converted into ice, would move in all directions from the region of greatest precipitation, because there the snow would be heaped up so as to create a sufficient slope of itself without the necessity of a previously existing high region for the purpose. Accordingly such areas of extraordinary precipitation have been located where the divergence of the striation made it convenient to have them, regardless of climatic and topographical conditions. Nothing approaching this occurs at the present day; and it is impossible to understand how it could have happened in former times, when, as we have every reason to believe, the laws governing precipitation must have been similar to what they now are.

Professor Dana, whose authority is almost exclusively followed by the younger workers in geology in this country, believes that the region from which the continental glacier advanced was situated "over the Canada water-shed, nearly north of Montreal." But this was only "its southern portion," from which the "broad ice-range stretched northward and northeastward" * — to what point is not stated. The difficulties of the very general non-coincidence of the striation with that which is demanded by this theory are passed over by Professor Dana very lightly. The fact is, however, that if we can place confidence in the work of the Canada Survey, and that of Professor Dawson, who has devoted much time to the study of the drift in the St. Lawrence Valley, the direction of the striæ and the character of the surface geology in that region are decidedly opposed to the theory of a continental ice sheet. The striation seems to be very generally limited to the vicinity of the water-courses, and to be in a marked degree parallel with them.†

That some of the alleged facts by which the theory of a general ice sheet extending over Northeastern America is supported are without foundation in truth, may be unhesitatingly affirmed. Thus the constantly repeated statement that Mount Ktaadn in Maine has been covered with ice up to an elevation of at least 4,385 feet above the sea is not in accordance with the long-continued and careful observations of Professor Hamlin, who could find, during three seasons of work on and about that mountain, no traces of rounded and polished surfaces (*roches moutonnées*) or of striation upon it. The occurrence of fossiliferous boulders, so often referred to as proof of the presence of ice, cannot be accepted as such, in view of the fact that the erosion of that region has been going on during indefinite geological ages, so that the whole topographical aspect of the mountain and its vicinity must have been very essentially changed from what it formerly was. That Ktaadn should have been passed over or even surrounded by a sheet of ice, variously estimated by the advocates of the theory of a continental glacier at from two to twelve miles in thickness, and exhibit no other signs of such an event than are offered by the occurrence of a few striated boulders of foreign rock on its sides, seems to the writer incredible.‡

* Manual of Geology, Third Edition, 1880, p. 587. In the first edition of the same work (1863) we find the following: "The whole northern portion of the continent down to the southern limit of the drift was covered by a vast and almost uninterrupted glacier." Motion was to the southward, because "to the north there was a universal barrier in the ice and snow of the universal glacier. Motion would therefore have been mainly to the southward, if it took place in any direction."

† The map given by Professor Dawson in his Notes on the Post-Pliocene Geology of Canada makes the southwest direction of the striation altogether the predominating one on the north side of the St. Lawrence and the Great Lakes, from Labrador to beyond Lake Superior.

‡ See Bulletin of the Museum of Comparative Zoölogy, Vol. VII. pp. 214, 215. That the occurrence of striated pebbles and boulders in the "slides" on Ktaadn is not by any means positive proof that a continental glacier once passed over that mountain, is the decided opinion of the present writer; but this subject will be alluded to

Much the same difficulty is experienced in making out that the White Mountains or the Adirondacks have ever been passed over by an ice sheet coming from the north. Vanuxem and Emmons assert that in the latter range the glaciation, as well as the distribution of the boulders, was from the centre in a radiating direction, and it is not known to the writer that this statement has been proved not to be correct. In the White Mountains the evidences of the descent of local glaciers from the higher regions towards the lower are very perceptible; the proof that the range has been buried under an ice sheet thousands of feet in thickness is not — to the present writer — by any means satisfactory.

The discovery of water-worn pebbles and boulders on or near the summit of Mount Washington cannot be accepted as evidence that a continental glacier has been there. To assume such to have been the case is simply another instance of the prevailing delusion that fragments of rock cannot be rolled and transported by water. A good illustration of the fact that the discovery in question is not satisfactory evidence of the former presence of ice is found in the isolated patches of gravel occurring on Clermont and Spanish Peak in the Sierra Nevada. These detrital deposits might as well be ascribed by the enthusiastic glacialist to the agency of a continental glacier as those observed on Mount Washington. But in the case of the Californian mountains we are sure that ice had nothing to do with the occurrence of the gravel where we find it. We know that these patches are fragments of old river channels, the evidence to this effect being abundant and convincing. The traces of a past luxuriant vegetation buried in the finer layers interstratified with the gravel are sufficient proof that this deposit was not made in the presence of ice.

Whenever the striation of any particular mountain region has been carefully studied, it has almost always been the case that the phenomena have been found to be of a much more complicated nature than had been previ-

again farther on. At the request of the writer, Professor Hamlin has furnished the following statement, in which are embodied conclusions based on observations made since the publication of the paper mentioned above: "The thin and blade-like form of that portion of Ktaadn upon which the two peaks are situated seems incompatible with the hypothesis that a moving ice-sheet has covered the mountain to its summit. Lower down than the highest of those flatter parts where scanty fragments of loose stratified rock occur, are several sharp crests having such directions that the supposed ice-sheet must have passed over them transversely. The continuance of such ridges to the present time, the fact that in my explorations of 1881 I found the lower northern extremity of Ktaadn to be bounded by steep cliffs or highly inclined faces, and the entire absence of surfaces approaching the condition of *roches moutonnées*, taken together, forbid to my mind the conclusion that Ktaadn has ever been, on its lower slopes or summit, acted upon by a continental ice-sheet."

ously supposed. A good instance of this will be found in the description of the striæ on and near Mount Monadnock, in New Hampshire, by G. A. Wheelock,* who says that he spent "many days during three years" in studying that region. His conclusions he thus sums up: "Do not these irregular striæ indicate a changeable and eddying current inconsistent with the motion of a glacier?"

Geologists have sought to overcome some of the difficulties presented by the striation in Northeastern America, by attributing to the continental ice sheet the faculty of moving in two or more directions at the same time. Thus Mr. Carll, one of the Assistants on the Second Pennsylvania Survey, intimates his belief that the same confluent mass of ice may flow "in different currents, at various horizons, with unequal velocities, and in divergent lines, dependent on circumstances controlling its movement."† Professor Dana also accounts for the fact that a portion of the striation conforms to the topography, while another part appears to be independent of it, by giving to the mass of ice the power of flowing in various directions at the same time. According to this view, while the lower portion of the ice mass was moving in the valleys towards different points — as, for instance, in the Hudson and Connecticut valleys, to the south, and in that of the Androscoggin to the east — the upper portion, over the whole country, was making its way in a general southeasterly direction, carried thither by the force of gravity, the slope between the region north of the St. Lawrence and the Atlantic coast being deemed sufficient to give the necessary motive force. The difficulty of the problem will be better appreciated after thus learning the extraordinary nature of some of the theories which have been originated in endeavoring to solve it.

That the continental ice sheet has been extended far beyond the limits which ought by any possibility to be claimed for it is, as the writer believes, perfectly evident. This has happened because inexperienced observers, having adopted the theory that all the drift phenomena are the work of a continental glacier, have covered every region with ice where any rolled detrital materials of northern origin could be found. Thus we often find the southern limits of the ice sheet of Northeastern America drawn so as to include a large part of Indiana, Illinois, Iowa, and Minnesota, while there is abundant evidence pointing clearly to the fact of its never having had anything like that extension to the south.

* American Naturalist, Vol. VII., 1873, pp. 466-470.

† J. F. Carll in Second Pennsylvania Report, III. p. 380.

In the opinion of the present writer, the geological importance of the so-called ground moraine has been greatly exaggerated. That a sheet of ice, such as is imagined by the advocates of the continental glacier, would have the enormous abrading power usually ascribed to it, and would transport and deposit the detrital material thus detached from the bed-rock in the manner in which the drift is distributed, is far from being proved. The statements of the various explorers of the glaciated region of Greenland indicate almost unanimously the unimportance or the entire absence of moraines under, upon, or in front of, the inland ice and its glacier appendages. The photographs taken at various points along the coast show the same thing. The region once occupied by the Greenland ice and now abandoned by it has no such masses of detritus piled up over its surface as there should be if ice was the great erosive agent, and if the distribution of the abraded material were similar to that shown to have taken place in the case of the Northern Drift.

That the aid of ice has been invoked, by geologists writing on the drift of this country, over large areas where in reality the work has been done exclusively by water, seems to the writer a proposition capable of being clearly established. It seems also to be beyond question that icebergs have played an important part, especially in carrying and distributing the large angular boulders which in many places rest upon the surface in such a manner as to show that they could not have been placed in their present positions by running water or by a general ice sheet.

The uncertainty attached to every phase of the Glacial epoch in Northeastern America makes all speculation extremely unsatisfactory in regard to the character and amount of the climatic or topographical changes which accompanied that epoch or were the cause of it. That it was a time of greater precipitation than is now taking place is evident enough; that it was also a period of intense cold, as is generally assumed, cannot be admitted: the palæontological evidence does not confirm this view. Even in the immediate vicinity of the glaciated regions the temperature was only moderately reduced.

That during a portion of the time, at least, when ice was doing its work in Northeastern America there was a much larger area of the continent under water than there is now, cannot be doubted. This would render the climate more oceanic, and be eminently favorable to the formation of ice in as high a northern latitude as that occupied by the region in question. A broad passage-way was certainly opened through the present Gulf of St. Lawrence, and perhaps also from Hudson's Bay, and through this icebergs may naturally have been carried in great numbers toward more southern regions.

SECTION V. — *Résumé and General Discussion.*

The facts brought forward in the second chapter of the present volume, and the discussion which followed in the succeeding one, were passed over in a rapid review at the close of that portion of the work which is devoted to the subject of desiccation.* It will now be proper to do the same for the present chapter, in which a large body of material has been laid before the reader, and in many cases with accompanying comments. Some repetition will be unavoidable; but it is thought that such a *résumé* as is here proposed is desirable, even if it adds somewhat to the size of the volume, especially as it will furnish an opportunity for enlarging on some points of special importance, and of introducing a few considerations which have not found a place in the preceding pages.

We have already seen most clearly that it is possible to lay aside all idea of explaining the phenomena of the so-called Glacial epoch, by referring them to the extension of a general or Polar ice-cap over the land of the northern hemisphere. The fact that this idea, so popular a few years ago among glacial geologists, may now be rejected without hesitation, is a proof that some progress has been made in this department of climatic geology. As already suggested, the explorations of the California Survey fifteen years ago showed so clearly the real character of the glaciation of the Cordilleras, and how unlike it was to that of Northeastern North America, that the idea of a general ice-cap on this continent had at once to be abandoned, while the more recent scientific explorations of Northern Asia have proved the same thing to be true for the Old World.

The entire body of facts presented brings out most clearly the true condition of things, namely, that the Glacial epoch was a local phenomenon, during the occurrence of which much the larger part of the land-masses of the globe remained climatologically entirely unaffected. We have seen how at the present time glaciers are limited to mountain ranges, and to such as are favorably situated with respect to prevailing moisture-bearing winds. We have also had abundant exemplification of the fact that high mountain

* See *ante*, p. 264.

regions, if so placed as to be out of the range of such winds, are only slightly covered with snow and are not the home of extensive glaciers.

We have learned that even in the high Polar latitudes, where the mean temperature is very low, much the larger part of the surface is free, during a considerable part of the year, from snow, and of course entirely destitute of glaciers. This is by far the most important point which we have been able to make in reference to the inquiry which forms the special subject of the present volume. Since a vast area of land remains uncovered by ice in spite of a low mean temperature, we are fully justified in asserting that a still greater increase of cold would not cover those regions with ice, or bring about the conditions of a Glacial epoch. On the contrary, it is evident that the opposite result would take place, or that those regions would become still more free from snow and ice than they are at the present time. The conditions of a Glacial epoch are not, therefore, to be sought for in a general diminution of the temperature. It is true that the regions in which the glaciers take their rise cannot be so warm that precipitation takes the form of rain; but the required low temperature must be confined to a limited area, and be brought about by local causes, and not be something in which all the other portions of the earth are sharers. There must be copious precipitation, which, although locally in the form of snow, can in reality only be the result of a high mean temperature in other regions. In short, warmth, as a phenomenon of general occurrence, is more indispensably necessary than cold, because the latter may always be produced, where locally wanted, by increase of elevation or by the shifting of the ocean currents.

The present writer is by no means the first to advocate the idea that a higher mean temperature was compatible with a greater extension of the glaciers. Already, as early as 1847, Lecoq took similar ground, defending his views with great skill; * although at the time his work was written the lack of accurate observation over so large a portion of the earth's surface placed him in a comparatively disadvantageous position, and he was hardly able to find a single geologist to support him. The present writer holds essentially the same views as those maintained by Lecoq, at least so far as concerns the here all-important point of the existence of larger ice masses being compatible with a higher mean temperature,† but has reached this

* See Lecoq's work, entitled Les Glaciers et les Climats, ou des Causes Atmosphériques en Géologie, Paris et Strasbourg, 1847.

† A single quotation from Lecoq's work will be all for which room can be spared: "Thus the phenomenon

conclusion from an entirely different starting-point and not following the same route as that taken by the French geologist. Having come to occupy the same ground with him, the writer has, as he believes, been able to fortify himself more strongly in his position than his predecessor in this line of investigation, but simply because the activity with which glacial phenomena have been observed during the five-and-thirty years since Lecoq wrote places at the command of present investigators a larger body of material than was available at that early date.

Ideas very similar to those of Lecoq were advocated, in 1864, by the eminent English chemist and physicist, Frankland, the gist of whose views may be gathered from the following quotation: "*The sole cause of the phenomena of the glacial epoch was a higher temperature of the ocean than that which obtains at present.*

"This hypothesis rests chiefly on the two following propositions: —

"1st. That a higher oceanic temperature would give rise to an increased evaporation, and consequently to an augmented atmospheric precipitation.

"2d. That this increased atmospheric precipitation would augment the average depth of permanent snow upon the ice-bearers, and would, within certain limits, depress the snow-line."*

When we pass in review the various portions of the earth where ice and snow once covered a greater area than they now do, we are struck by the fact that, with one exception, these are regions where glaciers still exist, so that the phenomena of the Glacial epoch were but a magnified form of present conditions. As illustrations of the various stages of complexity thus exhibited in different regions, we can indeed trace all the intermediate stages between the slight and hardly perceptible increase, as in the case of the glaciers around the volcanic cones of South America, to that of the formerly glaciated region of Northeastern North America, where we find almost nothing to guide us in connecting the conditions of the present with the phenomena of the past. We may take, first, the Caucasus, where the ancient glaciers existed under precisely similar topographical conditions to

of the Alpine erratic blocks, with which the attention of geologists in these later days has been so much occupied, depends entirely on a cause which has not yet been sufficiently appreciated, and which one at first naturally hesitates in accepting. It does not depend on a cold period [période frigorifique], as some geologists suppose, but, on the contrary, on an elevated temperature." (l. c. p. 315.)

* On the Physical Cause of the Glacial Epoch, Philosophical Magazine, Vol. XXVII., 1864, p. 328. Professor Frankland seems to have changed his views somewhat after the publication of this paper; but he still thought "a high temperature of the surface of the sea a necessary condition of the glacial epoch." (See Experimental Researches in Pure, Applied, and Physical Chemistry, by E. Frankland, London, 1877, p. 960.)

those which now prevail in that range, where there was no advance of the ice beyond the limits of the range itself, and where the glaciers themselves still remain, having a development not much inferior to that which they had during the Glacial epoch.

In the Sierra Nevada of California, again, we have now precisely similar topographical conditions to those which existed at the time large glaciers were developed there; but these have entirely disappeared, leaving hardly the faintest traces of their former existence so far as the actual presence of ice is concerned, but abundant proof of it in the form of moraines, striæ, and other easily recognized phenomena. Here we find still a condition of things in harmony with itself, and not presenting any serious difficulties as regards explanation. The decrease and disappearance of the glaciers in the Sierra Nevada is an occurrence in close relation with the desiccation which has long been going on in the adjacent region on the east. It is but a short time since the ice disappeared. Indeed, it may be said without the slightest fear of error that this disappearance took place long after the existence of the human race began in that region, and that when these glaciers were at their maximum the valley at the base of the range was no less habitable than it now is, and that nothing whatever indicates that a "Glacial epoch" ever prevailed there, or that the character of the vegetation underwent any essential change immediately before or after the time when ice covered the summits of those mountains.

Passing to the Alps, however, we find ourselves in the presence of more complicated phenomena. The past glaciation was indeed subordinate to the topography, and the glaciers have by no means disappeared, although much reduced in size. If the ice flows at the time of their greatest development passed beyond the limits of the range and spread themselves on the plain at its base, as supposed by some, this did not take place on any very extensive scale, so that the condition of things during the Alpine Glacial epoch was not one difficult of comprehension. At least we are not obliged to assume that the earth's climate underwent a radical change, because there were ice flows four or five times as long as any now existing. The extraordinary amount of shrinking which these glacial masses have undergone within the past fifty years, without any perceptible corresponding climatic change, is sufficient proof of the correctness of this view.

The Scandinavian glacial development was decidedly more complicated and on a grander scale than the Alpine; but the principal facts connected with the later geological history of that region have been already presented and commented on to the full extent which the space at the writer's command has permitted. That the ice sheet extended much farther beyond the base of the range than was the case in the Alps, cannot be doubted. The occurrence of the åsar forms a marked feature of Scandinavian glacial geology, not paralleled in the slightest degree by anything seen in the Alpine region, and in regard to the explanation of which the most discordant opinions have been and still are held by those who have devoted much time to their examination. Even in the Scandinavian Range, however, we have still remaining extensive *névé* fields, with numerous large glaciers issuing from them, while the striation over regions now abandoned by the ice seems to point unmistakably towards the axis of the still partly glaciated range, as has been set forth in the preceding pages. We thus find ourselves, in discussing the phenomena of the Scandinavian Glacial epoch, guided by present conditions to such an extent that we have but little difficulty in recognizing the general sequence of events, the details of which have been worked out with so much care and skill by the Swedish Geological Survey.

We next pass to a region where the Glacial phenomena exhibit the highest degree of complexity. We are beset with difficulties when we attempt to solve the problem presented by the Northern Drift in Northeastern America. It is indeed remarkable what dissimilar conditions are presented on the two opposite sides of this continent; but the complications of our Drift region have already been the subject of sufficient comment, and we need not enlarge farther upon them. Absence of a definitely known centre of glaciation; extreme complexity in the direction of the striation; proofs of the former presence of the sea over a part of the region, and of fresh water over another extensive portion; enormous accumulations of detrital material evidently deposited by water; occasional peculiar transportation of boulders in a manner not in harmony with anything we see ice doing at the present time; occurrence of linear accumulations of sand, gravel, and boulders closely resembling the åsar in character; proofs in some parts of the Drift region of the prevalence during the Glacial epoch of a colder climate, and in others of one warmer than that now existing — these are some of the difficulties which must be met by those who undertake to solve the problem of the Northern Drift of Northeastern America. That the assumption of a lower mean temperature of the earth would be of no assistance to the investigator in surmounting these difficulties seems to the writer to have been clearly established in the course of the present chapter.

Before closing, a few words must be said in regard to certain climatic theories which have at different times been much in vogue among geologists, and of which, thus far in the present work, only a passing notice has been taken. Allusion is here made to the views held by Adhémar, Croll, and others, according to which there has been during the geological ages a recurrence or cyclical succession either of cold and warm periods, or, if not of these, of such as were favorable to the development of ice and snow alternately on the two hemispheres. The essential feature of these theories of recurrent periods, or cycles of conditions tending to bring about glaciation, is that the northern and southern halves of the globe are, at different epochs, differently situated with regard to the sun. It was Adhémar's idea that the southern hemisphere is now in a glaciated condition, because the winter there is several days longer than in the other hemisphere. The theory of Croll, on the other hand, is based on the fact that the eccentricity of the earth's orbit is subjected to a cyclical change, in consequence of which its distances from the sun in perihelion and aphelion vary to a considerable amount. Mr. Croll believes that the result of the aphelion taking place in winter, during a period of maximum eccentricity, would produce such a climatic condition as would bring about a "Glacial epoch" in the hemisphere thus affected.

The first point, then, to which attention would naturally be turned, in endeavoring to make out whether these cyclical theories had some substantial basis of fact on which to rest, would be, whether geological and palæontological investigations proved that such recurrent changes as are demanded by these theories have ever really taken place.

If, as the reader will easily comprehend, there has been a cyclical recurrence of conditions resulting in periods of alternate glaciation and non-glaciation of the two hemispheres, then all that has been stated in the previous chapter in regard to persistent change in one direction, in consequence of the diminution of the sun's radiating power, would have to be set down as naught, unless it could be shown that evidence of refrigeration similar in importance and amount to that presented as proof of a warmer climate during variousgeological epochs had been overlooked or kept back designedly. If there has been a recurrence of changes from cold to warm, or from conditions favoring the formation of ice to those of a contrary nature, then it is not possible that the evidence should all be on the side of diminution of temperature with the progress of the geological ages. Yet such, in reality, appears to be the case. While all will admit that the proofs of a former higher temperature in various regions in pre-Glacial times are manifold and such as cannot possibly be set aside, it will be found impossible to show anything of essential importance of an opposite character. Nor has such proof at any time been brought forward by the advocates of cyclical changes of climate.

The principal support of the theory of a succession of Glacial epochs during the geological ages is to be found in the alleged occurrence of a few boulders in some of the older formations, striated in a manner resembling the work of ice during the Glacial epoch proper. When, however, we consider that masses of earth or of rock having boulders projecting from their sides or bottoms must be striated when forcibly moved in contact with hard substances, and when we reflect that such motion must occasionally, if not often, have taken place under other circumstances than those connected with the existence of moving ice masses, it becomes evident that striation is not a sufficient proof of an entire change of climatic conditions such as is demanded by the cyclical theory here under discussion. Every one familiar with the interior of mines has had occasion to see repeatedly, and as one of the commonest of phenomena, how striated surfaces are produced by motion of rock masses against each other; and it is easy to understand how fragments of such striated materials might become loosened from their fixed position, and, after being more or less acted on by water or other erosive agencies, take on an appearance not easily to be distinguished from that presented by pebbles or boulders which have been actually striated by ice.

The inspection of the bed of almost any recent great rock avalanche in a mountain region will not fail to result in the discovery of striated and scratched surfaces which from their freshness and other characters will be recognized at once, by an experienced eye, as having been formed by the slide itself.*

Some even go so far as to see the work of ice in every accumulation

* The writer examined with care, many years ago, the locality of the great avalanche mentioned by Dante (Inferno, XII. 4, 10), called I Slavini di San Marco, and which probably took place in 845. It is on the route from Trent to Verona. Here the scorings and striation of the tract over which the avalanche passed, more than a thousand years ago, are still most conspicuous. Their character, position, and direction with regard to the line of the fallen masses of rock are such that there can be no question as to their nature, or as to their having been really made by the avalanche itself.

of boulders, having apparently no recognition of the fact that there is any erosive and transporting agent except ice. Such an idea cannot be admitted as having the slightest claims to consideration. One must be blind not to see that the bulk of the water-worn boulders and pebbles formed at the present time in glacier regions consists simply of material thrown down in an angular form on the glacier, carried upon its surface in the same condition, and dumped at its terminus, where it remains unchanged until water has access to it, and deprives it of its morainic character. The ice is not by any means the real agent of the formation of the boulder, which would have lost its angular shape and acquired a rounded form whenever exposed to the action of water had there been no glacier in its way to receive it when it was loosened from the overhanging rocky wall and fell downward into the valley.

When we take into consideration the relative positions of the land masses of the two hemispheres, the peculiar conditions of things in the southern, and the very different extent to which various portions of the northern are covered by snow or ice, it seems impossible to admit for a moment that astronomical causes of the kind indicated by Adhémar or Croll can at the present time have any perceptible influence on the glacial conditions of those regions. And if they are not now thus influential, so there is every reason to believe that they were inoperative in the past. The weight of the highest authorities is decidedly against the theories of both Adhémar and Croll from the stand-point of astronomical science; while it is believed that these theories are equally at variance with the conclusions of the most eminent climatologists of the present day. At all events, the evidence in favor of a cyclical recurrence of cold or glacial periods sinks into insignificance when compared with that indicating a progressive diminution of the temperature on the earth's surface during the geological ages, and from the very earliest times when land began to exist from the conditions of which light on this subject could be procured.