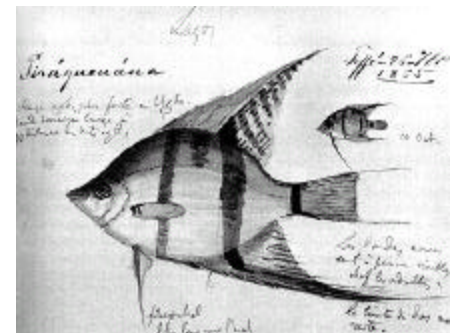




Louis Agassiz



Angelfish by Jacques Burkhart - Thayer Expedition

character is as natural as that by which earlier ichthyologists, and even travellers of very recent date, have confounded some fresh water fishes from the Upper Amazons of the genus *Pterophyllum* (Heckel) with the marine genus *Platax*.

5. As I have stated in the beginning, I am satisfied that the unstratified clay deposit of Rio and its vicinity is genuine glacial drift, resulting from the grinding of the loose materials interposed between the glacier and the solid rock in place, and retaining to this day the position in which it was left by the ice. Like all such accumulations, it is totally free from stratification. If this be so, it is evident, on comparing the two formations, that, the ochraceous sandy clay of the Valley of the Amazons has been deposited under different circumstances; that, while it owes its resemblance to the Rio drift to the fact that, its materials were originally ground by glaciers in the upper part of the valley, these materials have subsequently been spread throughout the whole basin and actually deposited under the agency of water.

seemed serious enough. It is but lately, that, in turning over the leaves of a journal, published some twelve or fifteen years ago, to look for a forgotten date, I was amused to find a formal announcement, under the signature of the greatest geologist of Europe, of the demise of the glacial theory. Since then it has risen, phoenix-like, from its own funeral pile. Even when I arrived in England, many of my friends would fain have dissuaded me from my expedition, urging me to devote myself to special zoological studies, and not to meddle with general geological problems of so speculative a character. "Punch" himself did not disdain to give me a gentle hint as to the folly of my undertaking, terming my journey into Scotland in search of moraines a sporting-expedition after "moor-hens." Only one of my older scientific friends in England, a man who in earlier years had weathered a similar storm himself, shared my confidence in the investigations looked upon by others as so visionary, and offered to accompany me in my excursion to the North of England, Scotland, and Wales. I cannot recur to that delightful journey without a few words of grateful and affectionate tribute to the friend who sustained me by his sympathy and guided me by his knowledge and experience. For many years I had enjoyed the privilege of personal acquaintance with Dr. Buckland, and in 1834, when engaged in the investigation of fossil fishes, I had traveled with him through parts of England and Scotland, and had derived invaluable assistance from his friendly advice and direction. To him I was indebted for an introduction to all the geologists and paleontologists of Great Britain, with none of whom, except Lyell, had I any previous personal acquaintance. Through him I obtained not only leave to examine all the fossil fishes in public and private collections throughout England, but the unprecedented privilege of bringing them together for closer comparison in the rooms of the Geological Society of London. A few years later he visited Switzerland, when I had the pleasure of showing him, in my turn, the glacial phenomena of my native country, to the study of which I was then devoting all my spare time. After a thorough survey of the facts I had collected, he became satisfied that my interpretation of them was likely to

up, -they will find they have covered the whole ground, and that the two theories are perfectly consistent with each other. I think the present disputes upon this subject will end somewhat like those which divided the Neptunic and Plutonic schools of geologists in the early part of this century; the former of whom would have it that all the rocks were due to the action of water, the latter that they were wholly due to the action of fire. The problem was solved, and harmony restored, when it was found that both elements had been equally at work in forming the solid crust of the globe. To the stranded icebergs alluded to above, I have no doubt, is to be referred the origin of the many lakes without outlet existing allover the sandy tract along our coast of which Cape Cod forms a part. Not only the formation of these lakes, but also that of our salt-marshes and cranberry-fields, I believe to be connected with the waning of the ice-period. I hope at some future time to publish in detail, with the appropriate maps and illustrations, my observations on our coast changes, -and upon other phenomena connected with the close of the glacial epoch in the United States. It is reversing the natural order of things to give results without the investigations which have led to them; and I should not have introduced the subject here, except to show that the fresh-water denudations and the oceanic encroachments which have formed the Amazonian Valley, with its river system, are not isolated facts, but that the process has been the same in both continents. The extraordinary continuity and uniformity of the Amazonian deposits are due to the immense size of the basin enclosed, and the identity of the materials contained in it. A glance at any geological map of the world will show the reader that the Valley of the Amazons, so far as any attempt is made to explain its structure, is represented as containing isolated tracts of Devonian, Triassic, Jurassic, cretaceous, tertiary, and alluvial deposits. As is shown by the above sketch, this is wholly inaccurate; and whatever may be thought of my interpretation of the actual phenomena, I trust that, in presenting for the first time the formations of the Amazonian basin in their natural connection and sequence, as consisting of three uniform sets of comparatively recent deposits, extending throughout the whole

mountains; wherever we find one of these ancient semicircular walls of unusual size, there we may be sure the glacier resolutely set its icy foot, disputing the ground inch by inch, while heat and cold strove for the mastery. There may have been a succession of cold summers, or, if now and then a warmer summer intervened, a colder one followed, so that the glacier regained the next year the ground it had lost during the preceding one, thus continuing to oscillate for a number of years along the same line, and adding constantly to the debris collected at its extremity. Wherever such oscillations and pauses in the retreat of the glacier occurred, all the materials annually brought down to its terminus were collected; and when it finally disappeared from that point, it left a wall to mark its temporary resting-place. By these semicircular concentric walls we can trace the retreat of the ice as it withdrew from the plain of Switzerland to the fastnesses of the Alps. It paused at Berne, and laid the foundation of the present city, which is built on an ancient moraine; it made a stand again at the Lake of Thun, and barred its northern outlet by a wall which holds its waters back to this day. Other moraines, though less distinct, are visible nearer the base of the Bernese Alps, and, above Meyringen, the valley is spanned by one of very large dimensions. Again, on the other side of the first chain of high peaks, the glacier of the Rhone, descending the valley toward the Lake of Geneva, has everywhere left traces of its ancient extension. We find the valley crossed at various distances by concentric moraines, until we reach the lake. There are no less than thirteen concentric moraines immediately below the present termination of the glacier of the Rhone, the one nearest to the ice and the last formed, marking its present boundary. Others are visible half a mile, a mile, and two or three miles beyond, near the villages of Obergestelen and Munster. One of the largest and finest of these ancient moraines of the glacier of the Rhone stands at Viesch, and extends across the whole valley, while the Rhone, already swollen by many mountain-torrents, has cut its way through it. Lower down, we meet with traces of other ancient glaciers, reaching laterally the main glacier, which occupied the centre of the valley. Such was the glacier of Viesch, when it extended as

now are. They rested upon the bottom deposits of the ice-fields, upon the glacial paste, consisting of clay, sand, pebbles, boulders, etc., underlying the ice. This bottom deposit did not, of course, present an even surface, but must have had extensive undulations and depressions. After the waters had been drained off from the more elevated ridges, these depressions would still remain full. In the lakes and pools thus formed, stratified deposits would be accumulated, consisting of the most minutely comminuted clay, deposited in thin laminated layers, or sometimes in considerable masses, without any sign of stratification; such differences in the formation being determined by the state of the water, whether perfectly stagnant or more or less agitated. Of such pool deposits overlying the drift there are many instances in the Northern United States. By the overflowing of some of these lakes, and by the emptying of the higher ones into those on a lower level, channels would gradually be formed between the depressions. So began to be marked out our independent river systems, -the waters always seeking their natural level, gradually widening and deepening the channels in which they flowed, as they worked their way down to the sea. When they reached the shore, there followed that antagonism between the rush of the rivers and the action of the tides, -between continental outflows and oceanic encroachments, -which still goes on, and has led to the formation of our eastern rivers, with their wide, open estuaries, such as the James, the Potomac, and the Delaware. All these estuaries are embanked by drift, as are also, in their lower course, the rivers connected with them. Where the country was low and flat, and the drift extended far into the ocean, the encroachment of the sea gave rise, not only to our large estuaries, but also to the sounds and deep bays forming the most prominent indentations of the continental coast, such as the Bay of Fundy, Massachusetts Bay, Long Island Sound, and others. The unmistakable traces of glacial action upon all the islands along the coast of New England, sometimes lying at a very considerable distance from the mainland, give an approximate, though a minimum, measure of the former extent of the glacial drift seaward, and the subsequent advance of the ocean upon the land. Like those of the

in the Canton of Valais, the inhabitants of the upper valleys adhered to the Protestant faith. Shut out from ordinary communication with the Protestant churches by the Bernese Oberland, the account states that these peasants braved every obstacle to the exercise of their religion, and used to carry their children over a certain road by the valley of Viesch, across the Alps, to be baptized at Grindelwald, on the farther side of the glaciers of Aletsch and Viesch. I could not understand this statement, for no such road exists, or could be conceived possible at present; nor was there any knowledge of it among the guides, intimate as they are with every feature of the region. Impressed, however, with the idea that there must be some foundation for the statement, I carefully examined the ground, and, penetrating under the glacier of Aletsch, actually found, a number of feet below the present level of the ice, the paved road along which these hardy people traveled to church with their children, and some traces of which are still visible. It has been almost completely buried, although here and there it reappears; but at this day it is completely impassable for ordinary travel. Evidence of a like character is found in a number of facts cited by Venetz in his celebrated paper upon the variations of temperature in the Swiss Alps, drawn from the parish and commune registers of the Canton of Valais. Among these are acts concerning the right to roads which are now either entirely hidden by ice or rendered nearly useless by the advance of the glacier, a lawsuit respecting the use of a forest which no longer exists but the site of which is covered by a glacier, and other records of a similar character. The only document so far as I know, previous to this century, which furnishes the means of delineating with any accuracy the former boundary of a glacier, is a topographical plan of the environs of the Grimsel, including the extremity of the Aar, making a part of Altomann's work upon the Alps. In 1740, Kapeler, a physician of Lucerne, undertook a journey to the mountains of the Aar, to visit certain crystal grottos, now well known, but then recently discovered. He prepared a map of these grottos and their vicinity, in which they are represented as being situated at some distance from the extremity of the glacier, in a the lower end of which is now

sea, would enable us to distinguish the work of the river from that of the ocean, and to prove that the denudation now going on is due in part to both. But besides this, I was so fortunate as to discover here unmistakable and perfectly convincing evidence of the onward movement of the sea. At the mouth of the Igarape Grande, both at Soure and at Salvaterra, on the southern side of the Igarape, is a sub-merged forest. Evidently this forest grew in one of those marshy lands constantly inundated, for between the stumps is accumulated the loose, felt-like peat characteristic of such grounds, and containing about as much mud as vegetable matter. Such a marshy forest, with the stumps of the trees still standing erect in the peat, has been laid bare on both sides of the Igarape Grande by the encroachments of the ocean. That this is the work of the sea is undeniable, for all the little depressions and indentations of the peat are filled with sea-sand, and a ridge of tidal sand divides it from the forest still standing behind. Nor is this all. At Vigia, immediately opposite to Soure, on the continental side of the Para River, just where it meets the sea, we have the counterpart of this submerged forest. Another peat-bog, with the stumps of innumerable trees standing in it, and encroached upon in the same way by tidal sand, is exposed here also. No doubt these forests were once all continuous, and stretched across the whole basin of what is now called the Para River. Since I have been pursuing this inquiry, I have gathered much information to the same effect from persons living on the coast. It is well remembered that, twenty years ago, there existed an island, more than a mile in width, to the northeast of the entrance of the Bay of Vigia, which has now entirely disappeared. Farther eastward, the Bay of Braganza has doubled its width in the last twenty years, and on the shore, within the bay, the sea has gained upon the land for a distance of two hundred yards during a period of only ten years. The latter fact is ascertained by the position of some houses, which were two hundred yards farther from the sea ten years ago than they now are. From these and the like reports, from my own observations on this part of the Brazilian coast, from some investigations made by Major Coutinho at the mouth of the Amazons, on its northern continental shore, near Macapa, and

The result of all these surveys has been a distinct recognition of not less than seven gigantic glaciers descending from the northern and western slopes of the Alps to the adjoining hilly plains of Switzerland and France. It is most interesting to trace their outlines upon a recent map of those countries, but it requires that kind of intellectual effort of the imagination without which the most brilliant results of modern science remain an unmeaning record to us. Let us, nevertheless, try to follow. The glacier of the Rhone, occupying the whole space between the Bernese and Valesian Alps, filled to overflowing the valley of the Rhone; at Martigny it was met by a large tributary from Mont Blanc, by the side of which it advanced into the plain beyond, filling the whole Lake of Geneva, and covering the beautiful Canton de Vaud and parts of Fribourg, Neuchatel, Berne, and Soleure, rising to the crest of the Jura, and in many points penetrating even beyond its outer range. To the east of this, the largest of all the ancient glaciers of Switzerland, we find the ancient glacier of the Aar, descending from the northern slope of the whole range of the Bernese Oberland. The glaciers that once filled the valley of Hasli, from the Grimsel to Meyringen, and those that came down from the Wetterhorner, the Schreckhorner, the Finster- Aarhorn, and the Jungfrau through the valleys of Grindelwald and Lauterbrunnen, united in a common bed, the bottom of which was the present basin of the lakes of Brienz and Thun. These were joined by the glaciers emptying their burden through the valley of the Kander. To these combined glaciers the formation of the terminal moraine of Thun must be ascribed. But before this had been formed, the glacier of the Aar, in its amplest extension, had also reached the foot of the Jura, without, however, spreading so widely as the glacier of the Rhone. Farther to the east Professor Guyot has traced the boundaries of three other colossal glaciers, one of which derived its chief supplies from the Alps of Uri, bringing with it all the tributaries which the main glacier coming down from the St. Gothard received right and left, in its course through the valley of the Reuss and the basins of the lakes of Lucerne and Zug. The second, born in the Canton of Glaris, followed mainly the present course of the Linth and the basin of the Lake

longitudinal channel of the Amazons itself, but also the lateral furrows through which its tributaries reach the main stream, and the network of anastomosing branches flowing between them; the whole forming the most extraordinary river system in the world. My assumption that the sea has produced very extensive changes in the coast of Brazil -changes more than sufficient to account for, the disappearance of the glacial wall which I suppose to have closed the Amazonian Valley in the ice-period -is by no means hypothetical. This action is still going on to a remarkable degree, and is even now rapidly modifying the outline of the shore. When I first arrived at Para I was struck with the fact that the Amazons, the largest river in the world, has no delta. All the other rivers which we call great, though some of them are insignificant as compared with the Amazons, -the Mississippi, the Nile, the Ganges, and the Danube, -deposit extensive deltas; and the smaller rivers also, with few exceptions, are constantly building up the land at their mouths by the materials they bring along with them. Even the little river Kander, emptying into the Lake of Thun, is not without its delta. Since my return from the Upper Amazons to Para I have made an examination of some of the harbor islands and also of parts of the coast, and have satisfied myself that, with the exception of a few small, low islands, never rising above the sea-level, and composed of alluvial deposit, they are portions of the mainland. detached from it, partly by the action of the river itself, and partly by the encroachment of the ocean. In fact, the sea is eating away the land much faster than the river can build it up. The great island of Marajo was originally a continuation of the Valley of the Amazons, and is identical with it in every detail of its geological structure. My investigation of the island itself, in connection with the coast and the river, leads me to suppose that, having been at one time an integral part of the deposits described above, at a later period it became an island in the bed of the Amazons, which, dividing in two arms, encircled it completely, and then, joining again to -form a single stream, flowed onward to the sea-shore, which in those days lay much farther to the eastward than it now does. I suppose the position of the island of Marajo at that time to have corresponded very nearly to the

modern glaciers of Europe, I look back upon them from another continent, and it seems to me that I have, as it were, a bird's-eye view of their whole extent. I confess that this distant retrospect of the subject has been to me almost as fascinating as were the researches of my earlier years in the same direction. I wish that I could present it to the minds of my readers with something of the attraction it possesses for me. I trust, however, that I have made it plain to them that the great mountain-chain of the Alps has been a central axis from which immense glaciers at one time descended in every direction, not only to its base, beyond which the lowlands extend in flat undulations, but to a greater or less distance over the adjoining plains; while at present they are confined to the higher valleys. The first attempts at a generalization concerning their origin started from the assumption that they must have been formed between the high ridges from which they seem to flow down. My own theory was also at first, that the upheaval of the Alps must, in some way or other, have been connected with these phenomena. But it soon became evident to me that these views were inadequate to account for the former presence of extensive glaciers in other parts of Europe; and even within the range of the Alps there were insuperable objections to their final admission. If the ancient glaciers had been first formed among the highest mountains, and extended, downwards into the plains, the largest and highest moraines ought to be the most distant, and to be formed of the most rounded masses; whereas the actual condition of the detrital accumulations is the reverse, the distant materials being widely spread, and true moraines being found only in valleys connected with great chains of lofty mountains. Again, all these moraines are within one another, -the most distant from the glacier to which they owe their origin, encircling all those which are nearer and nearer to it within the same glacial basin. As no glacier could reach its farthest moraine without pushing forward all the intervening loose materials, it is self-evident that the outer moraines were first formed, while those nearer the glacier were built up subsequently, in the order in which they follow one another from the lower valleys to the higher levels at which alone glaciers exist at present. Thus we

on the very borders of the snow and ice fields in Switzerland. The fact that these were accumulated in a glacial basin would, indeed, at once account for the traces of vegetable life, and for the absence, or at least the great scarcity, of animal remains in these deposits. For while fruits may ripen and flowers bloom on the very edge of the glaciers, it is also well known that the fresh-water lakes formed by the melting of the ice are singularly deficient in life. There are, indeed, hardly any animals to be found in glacial lakes. The second formation belongs to a later period, when, the whole body of ice being more or less disintegrated, the basin contained a larger quantity of water. Besides that arising from the melting of the ice, this immense valley bottom must have received, then as now, all which was condensed from the atmosphere above, and poured into it in the form of rain or dew. Thus an amount of water equal to that now flowing in from all the tributaries of the main stream must have been rushing towards the axis of the valley, seeking its natural level, but spreading over a more extensive surface than now, until, finally gathered up as separate rivers, it flowed in distinct beds. In its general movement toward the central and lower part of the valley, the broad stream would carry along all the materials small enough to be so transported, as well as those so minute as to remain suspended in the waters. It would gradually deposit them in the valley bottom in horizontal beds, more or less regular, or here and there, wherever eddies gave rise to more rapid and irregular currents, characterized by torrential stratification. Thus has been consolidated ill the course of ages that continuous sand formation spreading over the whole Amazonian basin, and attaining a thickness of eight hundred feet. While these accumulations were taking place within this basin, it must not be forgotten that the sea was beating against its outer walls, against that gigantic moraine which I suppose to have closed it at its eastern end. It would seem that, either from this cause, or perhaps in consequence of some turbulent action from within, a break was made in .this defense, and, the waters rushed violently out. It is very possible that the waters, gradually swollen at the close of this period by the further melting of the ice, by the additions poured in from lateral tributaries, by the

Viesch, built on such moraines, with the river running through their centre. If we need further confirmation of the fact that these accumulations on either side of this and other Swiss lakes are ancient lateral moraines, we have it in their connection with the walls of a like nature at their lower end, where we find again transverse moraines barring their outlet, and also on the continuity of long trains of fragments of similar rocks extending side by side across wide plains for great distances without mixture. From the beginning of my investigations upon the glaciers, I have urged these two points as most directly proving their greater extension in former times, and more recent researches constantly recur to this kind of evidence. All our lakes would be filled with loose materials, had their basins not been sheltered by ice against the encroachments of, well river-deposits during the transportation of the erratic boulders to the farthest limits of their respective areas. All the continuous trails of rocks derived from the same locality would have been scattered over wide areas, had they not been carried along in unyielding tracks like moraines. On a small scale the waters of the Rhone and of the Arve recall to this day such a picture. There are few travellers in Switzerland who have not seen these two rivers, where they flow side by side, at the southern extremity of the lake, meeting, but not mingling, the different color of their water marking the two parallel currents. In old times, when the glaciers filled all the valleys at the base of Mont Blanc, and to the east of it, uniting in the valley through which now runs the river Rhone, the glacier of the Arve came down to meet the ice from the valley of the Rhone, in the same manner as the river Arve now comes to meet the waters of the Rhone where they rush out from the southern end of the lake. This would be the proper place to consider the formation of the lakes of Switzerland, as well as their preservation by the agency of glaciers. But this subject is so intricate, and has already given rise to so many controversies which could not be overlooked in this connection, that I prefer to pass it over altogether in silence. Suffice it to say that not only are most of the lakes of Switzerland hemmed in by transverse moraines at their lower extremity, but the lakes of Upper Italy, at the foot of

and over again, grinding all the materials beneath it into a fine powder or reducing them to small pebbles, and it must have accumulated at its lower end a moraine of proportions as gigantic as its own; thus building a colossal sea-wall across the mouth of the valley. I shall be asked at once whether I have found here also the glacial inscriptions, -the furrows, striae, and polished surfaces so characteristic of the ground over which glaciers have travelled. I answer, not a trace of them; for the simple reason that there is not a natural rock surface to be found throughout the whole Amazonian Valley. The rocks themselves are of so friable a nature and the decomposition caused by the warm torrential rains and by exposure to the burning sun of the tropics so great and unceasing, that it is hopeless to look for marks which in colder climates and on harder substances are preserved through ages unchanged. With the exception of the rounded surfaces so well known in Switzerland as the roches moutonnees, heretofore alluded to, which may be seen in many localities, and the boulders of Errere, the direct traces of glaciers as seen in other countries are wanting here. I am, indeed, quite willing to admit that, from the nature of the circumstances, I have not here the positive evidence which has guided me in my previous glacial investigations. My conviction in this instance is founded, first, on the materials in the Amazonian Valley, which correspond exactly in their character to materials accumulated in glacier bottoms; secondly, on the resemblance of the upper or third Amazonian formation to the Rio drift, 5. of the glacial origin of which there cannot, in my opinion, be any doubt; thirdly, on the fact that this fresh-water basin must have been closed against the sea by some powerful barrier, the removal of which would naturally give an outlet to the waters, and cause the extraordinary denudations, the evidences of which meet us everywhere through- out the valley. On a smaller scale, phenomena of this kind have long been familiar to us. In the present lakes of Northern Italy, in those of Switzerland, Norway, and Sweden, as well as in those of New England, especially in the State of Maine, the waters are held back in their basins by moraines. In the ice-period these depressions were filled with

nine thousand feet, and across the whole plain of Switzerland, as I have stated, one may trace the glaciers by their moraines, by the masses of rock they have let fall here and there, by the drift they have deposited, to the very foot of the opposite chain, where they have dropped their boulders along the base of the Jura. Ascending that chain, one finds the grooved, polished, and scratched surfaces to its summit, on the very crest of which boulders entirely foreign to the locality are perched. Follow the range down upon the other side and you find the same indications extending into the plains of Burgundy and France beyond. With a chain of evidence so complete, it seems to me impossible to deny that the whole space between the opposite chains of the Alps and the Jura was once filled with ice; that this mass of ice completely covered the Jura, with the exception of a few high crests perhaps, rising island-like above it, and mounted to a height of some nine thousand feet upon the Alps, while it extended on the one side into the northern plain of Italy, filling all its depressions, and on the other down to the plains of Central Europe. The only natural inference from these facts is, that the climatic conditions leading to their existence could not have been local; they must have been cosmic. When Switzerland was bridged across from range to range by a mass of ice stretching southward into Lombardy and Tuscany, northward into France and Burgundy, the rest of Europe could not have remained unaffected by the causes which induced this state of things. It was this conviction which led me to seek the traces of glaciers in Great Britain. I had never been in the regions I intended to visit, but I knew the forms of the valleys in the lake-country of England, in the Highlands of Scotland, and in the mountains of Wales and Ireland, and I was as confident that I should find them crossed by terminal moraines and bordered by lateral ones, as if I had already seen them. The reader must not suppose, when I describe these walls formed of the debris of the glacier as consisting of boulders, stones, pebbles, sand, and gravel, a rough accumulation of loose materials indiscriminately thrown together, that we find the ancient moraines presenting any such appearance. Time, which mellows and softens all the wrecks of the past, has clothed them with turf, grassed them

philosopher wrote these lines, he had no idea how much these deposits extended beyond the field of his observations. Indeed, they are not limited to the main bed of the Amazons; they have been followed along the banks of its tributaries to the south and north as far as these have been ascended. They occur on the margins of the Huallaga and the Uayale, on those of the Ica, the Jutahy, the Jurua, the Japura, and the Purus. On the banks of the Japura, where Major Coutinho has traced them, they are found as far as the Cataract of Cupati. I have followed them along the Rio Negro to its junction with the Rio Branco; and Humboldt not only describes them from a higher point on this same river, but also from the valley of the Orinoco. Finally, they may be tracked along the banks of the Madeira, the Tapajos, the Xingu, and the Tocantins, as well as on the shores of the Guatuma, the Trombetas, and other northern effluents of the Amazons. The observations of Martius, those of Gardner, and the recent survey above alluded to, made by my assistant, Mr. St. John, of the valley of the Rio Guruguea and that of the Rio Paranyba, show that the great basin of Piauhy is also identical in its geological structure with the lateral valleys of the Amazons. The same is true of the large island of Marajo, lying at the mouth of the Amazons. And yet I believe that even this does not cover the whole ground, and that some future writer may say of my estimate, as I have said of Humboldt's, that it falls short of the truth; for, if my generalizations are correct, the same formation will be found extending over the whole basin of the Paraguay and the Rio de la Plata, and along their tributaries, to the very heart of the Andes. Such are the facts. The question now arises; how were these vast deposits formed? The easiest answer, and the one which most readily suggests itself, is that of a submersion of the continent at successive periods to allow the accumulation of these materials, and its subsequent elevation. I reject this explanation for the simple reason that the deposits show no sign whatever of a marine origin. No sea-shells nor remains of any marine animal have as yet been found throughout their whole extent, over a region several thousand miles in length, and from five to seven hundred miles in width. It is contrary to all our knowledge of geological deposits to

growing grandeur of these ancient glaciers, even while they were retreating into the heart of the Alps. In proportion as they left the plain, the landscape must have gained in imposing effect in consequence of the isolation of these immense masses of ice, which in their united extension may have recalled rather the immensity of the ocean, than the grandeur of Alpine scenery.

2. This map, with all its details and measurements, is reproduced (Pl V. fig. 1) in my "Systeme Glaciare," It was accompanied by an explanatory paper in the form of a letter to Altmann, then Professor at Berne.

THE PARALLEL ROADS OF GLEN ROY IN SCOTLAND

THERE are phenomena in nature which give the clew to so many of its mysteries, that their correct interpretation leads at once to broad generalizations and to the rapid advance of science in new directions. The explanation of one very local and limited problem may clear up many collateral ones, when its solution includes the answer to a whole set of kindred inquiries. The "parallel roads" of Glen Roy offer such a problem. For half a century they have been the subject of patient investigation and the boldest speculation. To them natural philosophers have returned again and again to test their theories, and until they are fully understood no steady or permanent advance can be made in the various views which they have suggested to different observers. The theory of the formation of lakes by barriers, presented by McCulloch and Sir T. Lauder-Dick, that of continental upheavals and subsidences, advocated by Sir Charles Lyell and Charles Darwin, that of inundations by great floods, maintained by Professor H. D. Rogers and Sir George Mackenzie, that of glacial action, brought forward by myself, have been duly discussed with reference to this difficult case; have found their advocates, all have met with warm opposition,

to their present level, by a denudation, more extensive than any thus far recorded in the annals of geology, which has given rise to all the most prominent hills and mountain chains along the northern bank of the river. Before seeking an explanation of these facts, let us look at the third and uppermost deposit. This deposit, essentially the same as the Rio drift, has been minutely described above; but in the north it presents itself under a somewhat different aspect. As in Rio, it is a clayey deposit, containing more or less sand and reddish in color, though varying from deep ochre to a brownish tint. It is not so absolutely destitute of stratification here as in its more southern range, though the traces of stratification are rare, and, when they do occur, are faint and indistinct. The materials are also more completely comminuted, and, as I have said above, contain hardly any large masses, though quartz pebbles are sometimes scattered throughout the deposit, and occasionally a thin seam of pebbles, exactly as in the Rio drift, is seen resting between it and the underlying sandstone. In some places this bed of pebbles even intersects the mass of the clay, giving it in such instances an unquestionably stratified character. There can be no question that this more recent formation rests unconformably upon the sandstone beds beneath it; for it fills all the inequalities of their denudated surfaces, whether they be more or less limited furrows, or wide, undulating depressions. It may be seen everywhere along the banks of the river, above the stratified sandstone, sometimes with the river mud accumulated against it; at the season of the enchente, or high water, it is the only formation left exposed above the water level. Its thickness is not great; it varies from twenty or thirty to fifty feet, and may occasionally rise nearly to a hundred feet in height, though this is rarely the case. It is evident that this formation also was once continuous, stretching over the whole basin at one level. Though it is now worn down in many places, and has wholly disappeared in others, its connection may be readily traced; since it is everywhere visible, not only on opposite banks of the Amazons, but also on those of all its tributaries, as far as their shores have been examined. I have said that it rests always above the sandstone beds. This is true, with one exception. Wherever the

with the rocky surfaces against which they move, as is the case with the glacier. On the contrary, being dashed to and fro, they strike and rebound, making a succession of blows, and never a continuous, uninterrupted pressure and friction. The same is true of all the marks made on rocky shores against which loose materials are driven by water-currents. They are separate, disconnected, fragmentary; whereas the lines drawn by the hard materials set in the glacier, whether light and fine or strong and deep, are continuous, often unbroken for long distances, and rectilinear. Indeed, we have seen that we have beneath every glacier a complete apparatus adapted to all the results described above. In the softer fragments path ground to the finest powder under the incumbent mass we have a polishing paste; in the hard materials set in that paste, whether pebbles, or angular rocky fragments of different sizes, or grains of sand, we have the various graving instruments by which the finer or coarser lines are drawn. Not only are these lines frequently uninterrupted for a distance of many yards, but they are also parallel, except when some change takes place in the thickness of the ice, which may slightly modify the trend of the mass, or where lines in a variety of directions are produced by the intermittent action of separate glaciers running successively at different angles over the same surfaces. The deeper grooves sometimes present a succession of short staccato touches, just as when one presses the finger vertically along some surface where the resistance is sufficient to interrupt the action without actually stopping it, a kind of grating motion, showing how firmly the instrument which produced it must have been held in the moving mass. No currents or sudden freshets carrying hard materials with them, even moving along straight path down hillsides or mountain-slopes, have ever been known to draw any such lines. They could be made only by some instrument held fast as in a vice by the moving power. Something of the kind is occasionally produced by the drag of a wheel grating over rocks covered with loose materials. It has been said that grounded ice or ice-bergs floating along a rocky shore might produce similar marks; but they will chiefly be at the level of high-water mark, and, if grounded, they will trend in various directions, owing to the rocking or rotating movement of

geological structure. In one word, all these hills were formerly part of a continuous formation, and owe their present outline and their isolated position to a colossal denudation. The surface of the once unbroken strata, which in their original condition must have formed an immense plain covered by water, has been cut into ravines or carried away over large tracts, to a greater or less depth, leaving only such portions standing as from their hardness could resist the floods which swept over it. The longitudinal trend of these hills is to be ascribed to the direction of the current which caused the denudation, while their level summits are due to the regularity of the stratification. They are not all table-topped, however; among them are many of smaller size, in which the sides have been gradually worn down, producing a gently rounded surface. Of course, under the heavy tropical rains this denudation is still going on, though in a greatly modified form. I cannot leave this serra without alluding to the great beauty and extraordinary extent of the view to be obtained from it. Indeed, it was here that for the first time the geography of the country presented itself to my mind as a living reality, in all its completeness. Insignificant as is its actual height, the serra of Errere commands a wider prospect than is to be had from many a more imposing mountain; for the surrounding plain, covered with forests, and ploughed by countless rivers, stretches away for hundreds of leagues in every direction, without any object to obstruct the view. Standing on the brow of the serra the numerous lakes intersecting the low lands at its base, you look across the Valley of the Amazons, as far as the eye can reach, and through its midst you follow for miles on either side the broad flood of the great river, carrying its yellow waters to the sea. As I stood there, panoramas from the Swiss mountains came up to my memory, and I fancied myself standing on the Alps, looking across the plain of Switzerland, instead of the bed of the Amazons, the distant line of the Santarem hills on the southern bank of the river and lower than the northern chain representing the Jura range. As if to complete the comparison, I found Alpine lichens growing among cactus and palms, and a crust of Arctic cryptogamous growth covered rocks between which sprang tropical flowers. On the northern flank of this serra I found the

comparison. I have not become acquainted with these marks in regions where glaciers no longer exist, and made a theory to explain their presence. I have, on the contrary, studied them where they are in process of formation. I have seen the glacier engrave its lines, plough its grooves and furrows in the solid rock, and polish the surfaces over which it moved, and I was familiar with all this when I found afterwards appearances corresponding exactly to those which I had investigated in the home of the present glaciers. I could therefore say, and I think with some reason, that this also is the work of the glacier acting in ancient times as it now acts in Switzerland. There is another character of glacial action distinguishing it from any abrasions caused by water, even if freighted with a large amount of loose materials. On any surface over which water flows we shall find that the softer materials have yielded first and most completely. Hard dikes will be left standing out, while softer rocks around them are worn away, - furrows will be eaten into more deeply, - fissures will be widened, - clay-slates will be wasted, - while hard sandstone or limestone and granite will show greater resistance. Not so with surfaces over which the levelling plough of the glacier has passed. Wherever softer and harder rocks alternate, they are brought to one outline; where dikes intersect softer rock, they are cut to one level with it; where rents or fissures traverse the rock, they do not seem to have been widened or scooped out more deeply, but their edges are simply abraded on one line with the adjoining surfaces. What-ever be the inequality in the hardness of the materials of which the rock consists, even in the case of pudding-stone, the surface is abraded so evenly as to leave the impression that a rigid rasp has moved over all the undulations of the land, advancing in one and the same direction and levelling all before it. Among the inequalities of the glacier-worn surfaces which deserve especial notice are the so-called roches moutonnees. They are knolls of a peculiar appearance, frequent in the Alps, and first noticed by the illustrious De Saussure, who designated them by that name, because, where they are numerous and seen from a distance, they resemble the rounded backs of a flock of sheep resting on the ground. These knolls are the result of the prolonged abrasion of masses of rocks

existed in the workings of nature; for though the organic combinations are so distinct in different climates and countries, they never wholly exclude each other. Every zoological and botanical province retains some link which binds it to all the rest, and makes it part of the general harmony. The Arctic lichen is found growing under the shadow of the palm on the rocks of the tropical serra, and the song of the thrush and the tap of the woodpecker mingle with the sharp discordant cries of the parrot and paroquet. Birds of prey, also, were not wanting. Among them was one called the Red Hawk, about the size of our kite, so tame that, even when our canoe passed immediately under the low branch on which he was sitting, he did not flyaway. But of all the groups of birds, the most striking as compared with corresponding groups in the temperate zone, and the one which reminded me the most distinctly of the fact that every region has its peculiar animal world, was that of the gallinaceous birds. The most frequent is the Cigana, to be seen in groups of fifteen or twenty, perched upon trees over-hanging the water, and feeding upon berries. At night they roost in pairs, but in the day-time are always in larger companies. In their appearance they have something of the character of both the pheasant and peacock, and yet do not closely resemble either. It is a curious fact, that, with the exception of some small partridge-like gallinaceous birds, all the representatives of this family in Brazil, and especially in the Valley of the Amazons, belong to types which do not exist in other parts of the world. Here we find neither pheasants, nor cocks of the woods, nor grouse; but in their place abound the Mutun, the Jacu, the Jacami, and the Unicorn (Crax, Penelope, Psophia, and Palamedea), all of which are so remote from the gallinaceous types found farther north, that they remind one quite as much of the bustard, and other ostrich-like birds, as of the hen and pheasant. They differ also from Northern gallinaceous birds in the greater uniformity of the sexes, none of them exhibiting those striking differences between the males and females which we see in the pheasants, the cocks of the woods, and in our barn-yard fowls. While birds abounded in such numbers, insects were rather scarce. I saw but few and small butterflies, and beetles were still more rare. The

the knolls are low and slope gently downward in every direction, they present the characteristic glacier-surfaces equally on all sides. This circumstance should be borne in mind by all who investigate the traces of glacier-action; for the inequality in the surfaces presented by the opposite sides of any obstacle in the path of the ice is often an important means of determining the direction of its motion. The other characteristic peculiarity of these roches moutonnees consists in the direction of the glacier-scratches, which ascend the slope to its summit in a direct line on one side, while they deviate, to the right and left on the other sides of the knoll, more or less obliquely according to its steepness. Occasionally, large boulders may be found perched on the very summit of such prominences. Their position is inexplicable by the supposition of currents as the cause of their transportation. Any current strong enough to carry a boulder to such a height would of course sweep it on with it. This phenomenon finds, however, an easy explanation in the glacial theory. The thickness of such a sheet of ice is of course less above such a hill or mound than over the lower levels adjoining it. Not only will the ice melt, therefore, more readily at this spot, but, as ice is transparent to heat, the summit of the prominence will become warmed by the rays of the sun, and will itself facilitate the melting of the ice above it. On the breaking up of the ice, therefore, such a spot will be the first to yield, and allow the boulders carried on the back of the glacier to fall into the hollow thus formed, where they will rest upon the projecting rock left uncovered. This is no theoretical explanation; there are such cases in Switzerland, where holes in the ice are formed immediately above the summit of hills or prominences over which the glacier passes, and into which it drops its burdens. Of course, where the ice is constantly renewed over such a spot by the onward progress of the glacier, these materials may be carried off again; but if we suppose such a case to occur at the breaking up of the glacier-period, in a locality from which the ice was disappearing forever, it is easy to account for the poising of these large boulders on prominent peaks or ledges. The appearances about the roches moutonnees, especially the straight scratches and grooves on the side up

where the red clay rose above the level of the water, a palm-thatched cabin stood on the low bluff, with a few trees about it. Such a house was usually the centre of a cattle-farm, and large herds might be seen grazing in the adjoining fields. Along the river-banks, where the country is chiefly open, with extensive low marshy grounds, the only palm to be seen is the Maraja. After keeping along the Rio Gurupatuba for some distance, we turned to the right into a narrow stream, which has the character of an Igarape 2. in its lower course, though higher up it drains the country between the serra of Errere and that of Tajury, and assumes the appearance of a small river. It is named after the serra, and is known as the Rio Errere. This stream, narrow and picturesque, and often so overgrown with capiro that the canoe pursued its course with difficulty, passed through a magnificent forest of the beautiful fan-palm, called here the Miriti (*Mauritia flexuosa*). This forest stretched for miles, over-shadowing a kind of underbrush, formed of many smaller trees and innumerable shrubs, some of which bore bright, conspicuous flowers. It seemed to me a strange spectacle,-a forest of monocotyledonous trees with a dicotyledonous undergrowth; the inferior plants thus towering above and sheltering the superior ones. Among the lower trees were many Leguminosae,-one of the most striking, called Fava, having a colossal pod. The whole mass of vegetation was woven together by innumerable lianas and creeping vines, in the midst of which the flowers of the Bignonia, with its open, trumpet shaped corolla, were conspicuous. The capim was bright with the blossoms of the mallow growing in its midst, and was often edged with the broad-leaved Aninga, a large aquatic Arum. Through such a forest, where the animal life was no less rich and varied than the vegetation, our boat glided slowly for hours. The number and variety of birds struck me with astonishment. The coarse sedgy grasses on either side were full of water birds, one of the most common of which was a small chestnut brown wading bird, the Jacana (*Parra*), whose toes are immensely long in proportion to its size, enabling it to run upon the surface of the aquatic vegetation as if it were solid ground. It was in the month of January, their breeding season, and at every turn of the boat we

decomposition to which they owe their separation from the solid rock is often still going on; Such debris are found everywhere about disintegrating rocks, and they constantly mingle with the loose fragments brought from a distance by various agencies. They are found upon and among the glacier-worn pebbles, especially where the latter have themselves been disturbed since their accumulation. They are also found among water-worn pebbles, wherever the rocky beds of our rivers or the rocky bluffs of our seashores crumble down. In investigating the character of loose materials transported from greater or less distances, either by the agency of glaciers or by water-currents, it is important at the very outset to discriminate between these deposits of older date and the local accessions mingling with them. Occasionally we may have also to distinguish between all these deposits and the debris brought down by land-slides, or by sudden, freshets transporting to a distance a vast amount of loose materials which are neither ice-worn nor water-worn. At Rossberg, for instance, in the Canton of Schwitz, the land- slide which buried the village of Goldau under a terrific avalanche, and filled a part of the Lake of Lauertz, spread an immense number of huge boulders across the valley, some of which even rolled up the opposite side to a considerable height. Many of these boulders might easily be mistaken for erratic boulders, were not the aggregate of these loose materials traceable to the hills from which they descended. In this case water had no part in loosening or bringing down this mass of fragments. They simply rolled from the declivity, and stopped when they had exhausted the momentum imparted to them by their weight. In the case of the debacle of Bagnes, above Martigny, in a valley leading to the St. Bernard, the circumstances were very different. A glacier, advancing beyond its usual limits and rising against the opposite mountain-slope, dammed up the waters of the torrent and caused a lake to be formed. The obstruction gave way in the course of time, and the waters of the lake rushed out, carrying along with them huge boulders and a mass of loose materials of all sorts, and scattering them over the plain below. Such an accumulation of debris differs from the pebbles and loose fragments found in river-beds. The comparatively short

valley so far as it could be seen on the river-banks and in the neighborhood of my different collecting stations. On my return, however, when my collections were completed, I was free to pursue this investigation, in which Major Coutinho was as much interested as myself. We determined to select Monte Alegre as the centre of our exploration, the serra in that region being higher than elsewhere. As I was detained by indisposition at Manaus, for some days, at the time we had appointed for the excursion, Major Coutinho preceded me, and had already made one trip to the serra, with some very interesting results, when I joined him, and we made a second journey together. Monte Alegre lies on a side arm of the Amazons, a little off from its main course. This side arm, called the Rio Gurupatuba, is simply a channel running parallel with the Amazons, and cutting through from a higher to a lower point. Its dimensions are, however, greatly exaggerated in all the maps thus far published, where it is usually made to appear as a considerable northern tributary of the Amazons. The town stands on an elevated terrace, separated from the main stream by the Rio Gurupatuba, and by an extensive flat, consisting of numerous lakes divided from each other by low alluvial land, and mostly connected by narrow channels. To the west of the town, this terrace sinks abruptly to a wide sandy plain called the Campos, covered with a low forest growth, and bordered on its farther limit by the picturesque serra of Etrere. The form of this mountain is so abrupt, its rise from the plain so bold and sudden, that it seems more than twice its real height. Judging by the eye, and comparing it with the mountains I had last seen the Corcovado, the Gavia and Tijuca range in the neighborhood of Rio, I had supposed it to be three or four thousand feet high, and was greatly astonished when our barometric observations showed it to be somewhat less than nine hundred feet in its most elevated point. This, however, agrees with Martius's measurement of the Almeirim hills, which he says are eight hundred feet in height. Major Coutinho and I reached the serra by different roads; he crossing the Campos on horseback with Captain Faria, the commander of our steamer and one or two other friends from Monte Alegre who joined our party, while I went by canoe. The

controversy among geologists respecting the nature and origin of the sheet of loose materials scattered over a great part of the globe turns upon it. The debris of which the drift consists are thrown together pell-mell, without any arrangement according to size or weight, larger and smaller fragments being mixed so indiscriminately that the heaviest materials may be on the very summit of the mass, and the lightest at the bottom in immediate contact with the underlying rock, or the larger pieces may stand at any level in the mass of finer ones. Impalpable powder coarse sand, rounded, polished, and scratched fragments of every size, are mixed together in a homogeneous paste, in which the larger materials are imbedded, to use a homely but expressive comparison, like raisins and currants in a pudding. The adhesive paste holding all these fragments together is, no doubt, the result of the friction to which the whole was subjected under the glacier, and which has worked some of the softer materials into a kind of cement. The mode of aggregation of water-worn materials is very different. Examine the shingle along our beaches; we find it so distributed as to show that the fading tide-wave has carried the lighter materials farther than the heavier ones, and the successive deposits exhibit an imperfect cross-stratification resulting from changes in the height of the tide and the direction of the wind. Moreover, in any materials collected under water we find the heavier ones at the bottom, the lighter on the top. It is true that large angular boulders may occasionally be found resting upon beach-shingle, but their presence in such a connection is easily explained. They may have been dropped there by floating icebergs, or have fallen from crumbling drift-cliffs. I should add, in speaking of drift-materials, that, while we find the large angular boulders resting above them, we occasionally find boulders of unusual size mingled with them; but, when this is the case, such massive fragments are more or less rounded, polished, and marked in the same way as the smaller pebbles, or as the surfaces over which the glacier has passed. This is important to remember, because, when we examine the drift in countries where the ice, during the glacier-period, overtopped nearly all the mountains, so that few fragments could fall from them upon its surface, we find

true nature. When their surface has been long exposed to the action of the atmosphere and to the heat of the burning sun, they look so much like clay slates of the oldest geological epochs, that, at first sight, I took them for primary slates, my attention being attracted to them by a regular cleavage as distinct as that of the most ancient clay slates. And yet at Tonantins, on the banks of the Solimoens, in a locality where their exposed surfaces had this primordial appearance, I found in these very beds a considerable amount of well-preserved leaves, the character of which proves their recent origin. These leaves do not even indicate as ancient a period as the Tertiaries, but resemble so closely the vegetation of to-day, that I have no doubt, when examined by competent authority, they will be identified with living plants. The presence of such an extensive clay formation, stretching over a surface of more than three thousand miles in length and about seven hundred in breadth, is not easily explained under any ordinary circumstances. The fact that it is so thoroughly laminated shows that, in the basin in which it was formed, the waters must have been unusually quiet, containing identical materials throughout, and that these materials must have been deposited over the whole bottom in the same way. It is usually separated from the superincumbent beds by a glazed crust of hard, compact sandstone, almost resembling a ferruginous quartzite. Upon this follow beds of sand and sandstone, varying in the regularity of their strata, reddish in color, often highly ferruginous, and more or less nodulous or porous. They present frequent traces of cross-stratification, alternating with regularly stratified horizontal beds, with here and there an intervening layer of clay. It would seem as if the character of the water basin had now changed, and as if the waters under which this second formation was deposited had vibrated between storm and calm, -had sometimes flowed more gently, and again had been tossed to and fro, giving to some of the beds the aspect of true; torrential deposits. Indeed, these sandstone formations present a great variety of aspects, Sometimes they are very regularly laminated, or assume even the appearance of the hardest quartzite, This is usually the case with the uppermost beds. In other localities, and more especially

drift-ponds, of our river-beds and estuaries, as well as the river-terraces standing far above the present water level. And now, if it be asked how much of this evidence for the former existence of glaciers is to be found in Great Britain, I answer, that there is not a valley in Switzerland where all these traces are found in greater perfection than in the valleys of the Scotch Highlands, or of the mountains of Ireland and Wales, or of the lake-region in England. Not a link is wanting to the chain. Polished surfaces, traversed by striae, grooves, and furrows, with a sheet of drift resting immediately upon them, extend throughout the realm,-the roches moutonnees raise their rounded backs from the ground there as in Switzerland, transverse moraines bar their valleys and lateral ones border them, and the boulders from the hillsides are scattered over the plains as thickly as between the Alps and the Jura, and are here and there perched upon the summits of isolated hills. This being the case, let us examine a little more closely the local phenomena connected with the ancient extension of glaciers in this region, and especially the parallel roads of Glen Roy. Among the Grampian Hills, a little to the northeast of Ben Nevis, lies the valley of Glen Roy, a winding valley trending in a northeasterly direction, and some ten miles in length. Across the mouth of this valley, at right angles with it, runs the valley of Glen Spean, trending from east to west, Glen Roy thus opening directly at its southern extremity into Glen Spean. Around the walls of the Glen Roy' valley run three terraces, one above the other, at different heights, like so many roads artificially cut in the sides of the valley, and indeed they go by the name of the "parallel roads." -These three terraces, though in a less perfect state of preservation, are repeated for a short distance at exactly the same levels on the southern wall of the valley of Glen Spean, just opposite the opening of the Glen Roy valley; that is, they make the whole circuit of Glen Roy, stop abruptly, on both sides, at its southern extremity, and reappear again on the opposite wall of Glen Spean.

Figure 1. (also see note 1.)

I should add, however, that all three do not come to this sudden

White Mountains, and the Alleghanies may very fairly be compared to the table-lands of Guiana and Brazil, and the Serra do Mar. Similar correspondences may be traced among the river systems. The Amazons and the St. Lawrence, though so different in dimensions, remind us of each other by their trend and geographical position; and while the one is fed by the largest river system in the world, the other drains the most extensive lake surfaces known to exist in immediate contiguity. The Orinoco, with its bay, recalls Hudson's Bay and its many tributaries, and the Rio Magdalena may be said to be the South American Mackenzie; while the Rio de la Plata represents geographically our Mississippi, and the Paraguay recalls the Missouri. The Parana may be compared to the Ohio; the Picomayo, Vermejo, and Salado rivers, to the River Platte; the Arkansas, and the Red River in the United States; while the rivers farther south, emptying into the Gulf of Mexico, represent the rivers of Patagonia and the southern parts of the Argentine Republic. Not only is there this general correspondence between the mountain elevations and the river systems, but as the larger river basins of North America -those of the St. Lawrence, the Mississippi, and the Mackenzie meet in the low tracts extending along the foot of the Rocky Mountains, so do the basins of the Amazons, the Rio de la Plata, and the Orinoco join each other along the eastern slope of the Andes. But while in geographical homology the Amazons compares with the St. Lawrence, and the Mississippi with the Rio de la Plata, the Mississippi and the Amazons, as has been said, resemble each other in their local geological character. They have both received a substratum of cretaceous beds, above which are accumulated their more recent deposits, so that, in their most prominent geological features, both may be considered as cretaceous basins, containing extensive deposits of a very recent age. Of the history of the Amazonian Valley during the periods immediately following the cretaceous, we know little or nothing. Whether the tertiary deposits are hidden under the more modern ones, or whether they are wholly wanting, the basin having, perhaps, been raised above the sea-level before that time, or whether they have been swept away by the tremendous inundations in the valley, which

the centre free into which Glen Roy opens, while, by the time the water had sunk to the level of the lowest terrace, one of these barriers, that to the east, must have been removed, for the lowest terrace, as I have said, is continuous throughout the eastern part of Glen Spean. 1. Prepossessed as I was with the idea of glacial agency in times anterior to ours, these phenomena appeared to me under a new aspect. I found the bottom of Glen Spean so worn by glacial action as to leave no doubt in my mind that it must have been the bed of a great glacier, and Dr. Buckland fully concurred with me in this impression. Indeed, the face of the country throughout that region presents not only the glacier-marks in great perfection, but other evidences of the ancient presence of glaciers. There are moraines at the lower end of Glen Spean, remodelled, it is true, by the action of currents, but still retaining enough of their ancient character to be easily recognized; and some of the finest examples of the roches moutonnees I have seen in Scotland are to be found at the entrance of the valley of Loch Treig, a lateral valley opening into Glen Spean on its southern side, and, as we shall see hereafter, intimately connected with the history of the parallel roads of Glen Roy. These roches moutonnees may very fairly be compared with those of the Grimsel, and exhibit all the characteristic features of the Alpine ones. One of them, lying on the western side of the valley where it opens into Glen Spean, is crossed by a trap-dike. The general surface of the hill, consisting of rather soft mica, has been slightly worn down by atmospheric agencies, so that the dike stands out some three quarters of an inch above it. On the dike, however, the glacier-marks extend for its whole length in great perfection, while they have entirely disappeared from the surrounding surfaces, so as to leave the dike thus standing out in full relief. This is an instructive case, showing how little disintegration has gone on since the drift-period. All the currents that have swept over it, all the rains that have beaten upon it, have not worn away one inch from the original surface of the hill. I have observed many other roches moutonnees in Scotland, especially about the neighborhood of Loch A we, Loch Fyne, and Loch Etive. In fact, they may be found in almost all the glens of Scotland, in the lake-region of

the crystalline masses first uplifted in the Amazonian valley. There is here no sequence, as in North America, of Azoic, Silurian, Devonian, and Carboniferous formations, shored up against each other by the gradual upheaval of the continent, although unquestionably older palaeozoic and secondary beds underlie, here and there, the later formations. Indeed, Major Coutinho has found palaeozoic deposits, with characteristic shells, in the valley of the Rio Tapajos, at the first cascade, and carboniferous deposits have been noticed along the Rio Guapore and the Rio Mamore. But the first chapter in the valley's geological history about which we have connected -and trustworthy data is that of the cretaceous period. It seems certain, that, at the close of the secondary age, the whole Amazonian basin became lined with a cretaceous deposit, the margins of which crop out at various localities on its borders. They have been observed along its southern limits, on its western outskirts along the Andes, in Venezuela along the shoreline of mountains, and also in certain localities near its eastern edge. I well remember that one of the first things which awakened my interest in the geology of the Amazonian Valley was the sight of some cretaceous fossil fishes from the province of Ceara. These fossil fishes were collected by Mr. George Gardner, to whom science is indebted for the most extensive information yet obtained respecting the geology of that part of Brazil. In this connection, let me say that here and elsewhere I shall speak of the provinces of Ceara, Piahy, and Maranham as belonging geologically to the Valley of the Amazons, though their shore is bathed by the ocean, and their rivers empty directly into the Atlantic. But I entertain no doubt, and I hope I may hereafter be able to show, that, at an earlier period, the northeastern coast of Brazil stretched much farther sea-ward than in our day; so far, indeed, that in those times the rivers of all these provinces must have been tributaries of the Amazons in its eastward course. The evidence for this conclusion is substantially derived from the identity of the deposits in the valleys belonging to these provinces with those of the valleys through which the actual tributaries of the Amazons flow; as, for instance, the Tocantins, the Xingu, the Tapajos, the Madeira, etc. Besides the fossils

mountains into Glen Spean had begun to retreat, and to form local limited glaciers, two of those lateral glaciers, one coming down from Ben Nevis on the southwest, the other from Loch Treig on the southeast, extended farther than the others and stretched across Glen Spean. These two glaciers for a long time formed barriers across the western and eastern extension of this valley, damming back the waters which filled Glen Roy and the central part of Glen Spean. Evidently the glacier descending from Loch Treig was the first to yield, for, by the time the Glen Roy lake had sunk to the level of the lowest terrace, the entrance to the eastern extension of the valley must have been free, otherwise the water could not have spread throughout that basin as we find it did; but it would seem that by the time the western barrier, or the glacier from Ben Nevis, was removed, the sheet of water was too far reduced to have left permanent marks of its outflow into the Great Glen, except by disturbing and remodelling the large moraines of the older Glen Spean glacier. There are faint indications of other terraces in Glen Roy, even at a higher level than the uppermost parallel road, owing their origin probably to the short duration of a higher level of the glacier-lake, when the great general glacier had not yet been lowered to a more permanent level determined by a limited circumscription within the walls of the valleys. There are other terraces in neighboring valleys at still different levels, Glen Gloy, for instance, where the one horizontal road was no doubt formed in consequence of the damming of the valley by a glacier from Loch Arkeig. Mr. Darwin has seen another in Glen Kinfillin, which I would explain by the presence of a glacier in the Great Glen, the marks of which are particularly distinct about the eastern end of Glen Garry. The evidence of the ancient presence of glaciers is no less striking in other parts of the Scotch Highlands. Between the south-eastern range of the Grampian Hills, in Forfarshire and Perthshire, and the opposite ridge of Sidlaw Hills, stretches the broad valley of Strathmore. At the time when Glen Spean received the masses of ice from the slopes of the western Grampian range, the glaciers descended from the valleys on the southern slope of the southeastern range and from those on the northern slope of

have had an opportunity of comparing on the spot his geological sections from the valley of the Piahy with the Amazonian deposits. There can be no doubt of the absolute identity of the formations in these valleys. Having arranged the work of my assistants, and sent several of them to collect and make geological examinations in other directions, I myself, with the rest of my companions, proceeded up the coast to Para. I was surprised to find at every step of my progress the same geological phenomena which had met me at Rio. As the steamer stops for a number of hours, or sometimes for a day or two, at Bahia, Maceio, Pernambuco, Parahiba, Natal, Ceara, and Maranham, I had many opportunities for observation. My friend Major Coutinho, already an experienced Amazonian traveller, first told me that this formation continued through the whole valley of the Amazons, and was also to be found on all of its effluents visited by him, although he had never thought of referring it to so recent a period. And here let me interrupt the course of my remarks to say, that the facts recorded in this article are by no means exclusively the result of my own investigations. They are in great part due to this able and intelligent young Brazilian, a member of the government corps of engineers, who, by the kindness of the Emperor, was associated with me in my Amazonian expedition. I can truly say that he has been my good genius throughout the whole journey, saving me, by his previous knowledge of the ground, from the futile and misdirected expenditure of means and time often inevitable in a new country, where one is imperfectly acquainted both with the people and their language. We have worked together in this investigation; my only advantage over him being my greater familiarity with like phenomena in Europe and North America, and consequent readiness in the practical handling of the facts, and in perceiving their connection. Major Coutinho's assertion, that on the banks of the Amazons I should find the same red, unstratified clay as in Rio and along the southern coast, seemed to me at first almost incredible, impressed as I was with the generally received notions as to the ancient character of the Amazonian deposits, referred by Humboldt to the Devonian, and by Martius to the Triassic

phenomena existed over the whole region. Among the localities of Scotland where the indications of glacial action are most marked is the region about Stirling. Near Stirling Castle the polished surfaces of the rocks with their distinct grooves and scratches show us the path followed by the ice as it moved down in a northeasterly direction toward the Frith of Forth from the mountains on the north-west. To the west of Edinburgh, also, there is a broad glacier track, showing that here also the ice was ploughing its way eastward to find an outlet on the shore. The western slope of the great Scotch range is no less remarkable for its glacier-traces. The heads of Loch Long, Loch Fyne, Loch Awe, and Loch Leven everywhere show upon their margins the, most distinct glacial polish and furrows, while from the trend of these marks and the distribution of the moraines, especially about Ben Cruachan, it is obvious that in this part of the country the glaciers moved westward and southward. About Aberdeen, on the contrary, they moved eastward, while in the vicinity of Elgin they advanced toward the north. It thus appears that the whole range of the Grampians formed a great centre for the distribution of glaciers, and that a colossal ice-field spread itself over the whole country, extending in every direction toward the lower lands and the sea-shore. As the glaciers, which now descend through all the valleys of the Alps, along their northern as well as their southern slopes, and in their eastern as well as their western prolongation, though limited, in our days, within the valley-walls, nevertheless once covered the plain of Switzerland and that of Northern Italy, so did the ice-fields of the Grampians during the greatest extension of the Scotch glaciers spread over the whole country. They also were, in course of time, reduced to local glaciers, circumscribed within the higher valleys of the more mountainous parts of the country, until they totally disappeared, as those of Switzerland would also have done, had it not been for the greater elevation of that country above the level of the sea. Scotland nowhere rises above the present level of perpetual snow, while in Switzerland the whole Alpine range has an altitude favorable to the preservation of glaciers. In the range of the Jura, however, which had at one time its local glaciers also, but which nowhere now rises above

from the more connected traces of glaciers, or extensive sheets of ice, resting directly upon the face of the country and advancing over it. There seems to be an inextricable confusion, in the ideas of many geologists, as to the respective action of currents, icebergs, and glaciers. The facts connected with these phenomena are in truth very different from each other, and easily recognized after the discrimination has once been made. As to the southward movement of an immense field of ice extending over the whole north, it seems inevitable, the moment we admit that snow may accumulate around the pole in such quantities as to initiate a pressure radiating in every direction. Snow alternately thawing and freezing must, like water, find its level at last. A sheet of snow ten or fifteen thousand feet in thickness, extending all over the northern and southern portions of the globe, must necessarily lead, in the end, to the formation of a northern and southern cap of ice, moving toward the equator. I have spoken of Tijuca and the Dom Pedro Railroad as favorable localities for studying the peculiar southern drift; but one meets it in every direction. A sheet of drift, consisting of the same homogeneous, unstratified paste, and containing loose materials of all sorts and sizes, covers the country. It is of very uneven thickness, -sometimes thrown into relief, as it were, by the surrounding denudations, and rising into hills, -sometimes reduced to a thin layer, -sometimes, as, for instance, on steep slopes, washed entirely away, leaving the bare face of the rock exposed. It has, however, remained comparatively undisturbed on some very abrupt ascents; as, for instance, on the Corcovado, along the path leading up the mountain, where there are very fine banks of drift, -the more striking from the contrast of their deep red color with the surrounding vegetation. I have myself followed this sheet of drift from Rio de Janeiro to the top of the Serra do Mar, where, just outside the pretty town of Petropolis, the river Piabanha may be seen flowing between banks of drift, in which it has excavated its bed; thence I have traced it along the beautiful macadamized road leading to Juiz de Fora in the province of Minas Geraes, and beyond this to the farther side of the Serra da Babylonia. Throughout this whole tract of country,

tracks of ancient glaciers might easily fancy himself crossing the ancient moraines at the foot of the northern slope of the range of Mont Blanc, through which the Arve has cut its channel, the valley of Chamouni standing in the same relation to Mont Blanc as the valley of Loch Nilly does to Ben Calcagh. I have dwelt thus at length on the glaciers of Great Britain because they have been the subject of my personal investigations. But the Scotch Highlands and the mountains of Wales and Ireland are but a few of the many centres of glacial distribution in Europe. From the Scandinavian Alps glaciers descended also to the shores of the Northern Ocean and the Baltic Sea. There is not a fiord of the Norway shore that does not bear upon its sides the tracks of the great masses of ice which once forced their way through it, and thus found an outlet into the sea, as in Scotland. Indeed, under the water, as far as it is possible to follow them through the transparent medium, I have noticed in Great Britain and in the United States the same traces of glacial action as higher up, so that these ancient glaciers must have extended not only to the sea-shore, but into the ocean, as they do now in Greenland. Nor is this all. Scandinavian boulders, scattered upon English soil and over the plains of Northern Germany, tell us that not only the Baltic Sea, but the German Ocean also, was bridged across by ice on which these masses of rock were transported. In short, over the whole of Northern Europe, from the Arctic Ocean to the northern borders of its southern promontories, we find all the usual indications of glacial action, showing that a continuous sheet of ice once spread over nearly the whole continent, while from all the mountain-ranges descended those more limited glacial tracks terminating frequently in transverse moraines across the valleys, showing, that, as the general ice-sheet broke up and contracted into local glaciers, every cluster or chain of hills became a centre of glacial dispersion, such as the Alps are now, such as the Jura, the Highlands of Scotland, the mountains of Wales and Ireland, the Alps of Scandinavia, the Hartz, the Black Forest, the Vosges, and many others have been in ancient times.

this superficial deposit studded with boulders, resting above the partially stratified metamorphic rock. Other excellent opportunities for observing this formation, also within easy reach from the city, are afforded along the whole line of the railroad of Dom Pedro Segundo, where the cuts expose admirable sections, showing the red, unstratified, homogeneous mass of sandy clay resting above the solid rock, and often divided from it by a thin bed of pebbles. There can be no doubt, in the mind of anyone familiar with similar facts observed in other parts of the world, that this is one of the many forms of drift connected with glacial action. I was, however, far from anticipating, when I first met it in the neighborhood of Rio, that I should afterwards find it spreading over the surface of the country, from north to south and from east to west, with a continuity which gives legible connection to the whole geological history of the continent. It is true that the extensive decomposition of the underlying rock, penetrating sometimes to a considerable depth, makes it often difficult to distinguish between it and the drift; and the problem is made still more puzzling by the fact that the surface of the drift, when baked by exposure to the hot sun, often assumes the appearance of decomposed rock, so that great care is required for a correct interpretation of the facts. A little practice, however, trains the eye to read these appearances aright, and I may say that I have learned to recognize everywhere the limit between the two formations. There is, indeed, one safe guide, namely, the undulating line, reminding one of roches moutonnees, and marking the irregular surface of the rock on which the drift was accumulated; whatever modifications the one or the other may have undergone, this line seems never to disappear. Another deceptive feature, arising from the frequent disintegration of the rocks and from the brittle character of some of them, is the presence of loose fragments, which simulate erratic boulders, but are in fact only detached masses of the rock in place. A careful examination of their structure, however, will at once show the geologist whether they belong where they are found, or have been brought from a distance to their present resting-place. While the features to which I have alluded are

of the upper roads. The outlet for the water at the period during which the second terrace was formed, not known when I visited Glen Roy, has been discovered by Mr. Milne-Holme, and also observed by Professor Jamieson. During the formation of the upper terrace the waters escaped through the western- most tributary of the river Spean, in the direction of the northeast corner of the woodcut, and during that of the lowest terrace, at the eastern end of Loch Laggan, also through the valley of the Spean. The state of preservation of the parallel roads is such as to prove that no disturbance of any importance can have taken place in the country since they were formed. Far from believing, therefore, that these remarkable shelves are ancient sea-beaches, I am prepared to maintain that, had the area occupied by them been submerged only for a few days, under an ocean rising and falling for several feet with every tide, no vestige would have been left of their former existence.

ICE-PERIOD IN AMERICA

IN the autumn of 1846, six years after my visit to Great Britain in search of glaciers, I sailed for America. When the steamer stopped at Halifax, eager to set foot on the new continent so full of promise for me, I sprang on shore and started at a brisk pace for the heights above the landing. On the first undisturbed ground, after leaving the town, I was met by the familiar signs, the polished surfaces, the furrows and scratches, the line-engraving of the glacier, so well known in the Old World; and I became convinced of what I had already anticipated as the logical sequence of my previous investigations, that here also this great agent had been at work, although it was only after a long residence in America, and repeated investigations of the glacial phenomena in various parts of the country, that I fully understood the universality of its action. A detailed description of these appearances could hardly

the drift phenomena along our Atlantic coast, showing also that at that period the ice-fields were not bounded by our present shore line, but extended considerably beyond it, over surfaces now occupied by the ocean. At a later time, during the shrinking and gradual disappearance of the ice-sheet, the ice no doubt, retreated within the shore islands. The aspect of the coast of New England must then have been very similar to that of Greenland in its colder portions. Mount Desert itself must have been a miniature Spitzbergen, and colossal icebergs floated off from Somes's Sound into the Atlantic Ocean, as they do nowadays from Magdalena Bay.

1. Those who wish to follow the localities indicated in this article should consult H. F. Walling's map of the State of Maine, published by J. Chace, Jr., Portland.
2. Leopold von Buch.

PHYSICAL HISTORY OF THE VALLEY OF THE AMAZONS

A YEAR or two ago I published in the "Atlantic Monthly," as part of a series of geological sketches, a number of articles on the glacial phenomena of the Northern hemisphere. Today I am led to add a new chapter to that strange history, taken from the Southern hemisphere, and even from the tropics themselves. I am prepared to find that the statement of this new phase of the glacial period will awaken among my scientific colleagues an opposition even more violent than that by which the first announcement of my views on this subject was met. I am, however, willing to bide my time; feeling sure that, as the theory of the ancient extension of glaciers in Europe has gradually

south, with occasional slight inclinations to the east or west, according to the minor inequalities of the surface. There is, however, no decided modification of their general trend in consequence of the range of hills intersecting them at right angles for nearly the whole width of the continent between latitudes forty-six and fifty; indeed, the Canadian, or, as they are sometimes called, the Laurentian Hills, did not form a more powerful barrier to the onward progress of the immense fields of ice covering the continent than did the small hummocks, or roches moutonnees, in the Swiss valleys to the advance of the Alpine glaciers. In fact, these low hills may be considered as a succession of roches moutonnees trending in a continuous ridge from east to west, over which the masses of northern ice have moved unimpeded to the latitude of the Ohio. Owing to the absence of high mountain-ranges over this vast expanse of land, the glacial phenomena of America are not grouped about special centres of dispersion, radiating from them as in Europe. During the greatest extension of the ice-fields, there were but few prominent peaks rising above them, and dropping here and there huge boulders on their surface, to be transported to great distances without losing their rough angular character. When the temperature under which these vast frozen masses had been formed rose again, the wasting ice must have yielded first on its southern boundary, gradually and uniformly retreating to the Arctic regions, without breaking up into distinct glacial regions, separated from one another, each with its local distribution of erratic boulders and glacier-marks radiating from circumscribed areas on higher levels as they occur everywhere in Europe. It is true that there are a few localities within the Alleghany range, on the Green and White Mountains, and in parts of Maine, where it is evident that local glaciers have had a temporary existence; but even throughout this eastern coast-range the elevation of the mountains is so slight, and their trend so uniform in a northeasterly and southwesterly direction through twenty degrees of latitude, that the localization of the phenomena is less marked than in Norway, Great Britain, or Switzerland. In short, the ice of the great glacial period in America moved over the continent as one continuous sheet, overriding nearly all the

upon which these moraines rest, consists of fine sand and loam with scratched pebbles. Seven or eight miles west of West Ellsworth the hills, consisting of clay about slates on edge, trending from east to west, are there abraded, and upon the polished surfaces of their levelled edges rest two other longitudinal moraines, with angular boulders of Dedham granite, running from north to south, and resting upon an extensive ground moraine containing many smaller rounded and striated boulders. Ten miles west of Ellsworth there is still another longitudinal moraine; but the largest of all these parallel moraines is about three miles farther west, that is, about thirteen miles west of Ellsworth. Half a mile south of Bucksport the clay slates are nearly vertical, and their upturned edges are evenly polished and scratched. These surfaces are partially covered with the mud of the Penobscot River. Similar facts may be traced all the way between Bucksport and Bangor. Everywhere the scratches point due north. The coast range east and west of Somes's Sound is divided into a series of hills by transverse valleys, in most of which there are small lakes formed by transverse moraines at their southern extremity. Beginning east, and not counting the less prominent peaks, we have, first, Newport Mountain; next, Kebo and Green Mountains; then, Jordan Mountain, Bobbey Mountain, Hadlock or Pond Mountain, and Westcot Mountain, all to the east of Somes's Sound; then follow Dog Mountain, Defile Mountain, Beach Hill, and West Mountain, all on the west side of Somes's Sound. Denning's Pond, which I have examined more in detail, lies between Dog Mountain and Defile Mountain. The road along the lake follows the eastern or left lateral moraine of the glacier, which once filled its basin; and the lake itself is hemmed in by a crescent-shaped terminal moraine at its southern extremity. The lakes, eleven in number, intervening between the other mountains, are likewise bordered by moraines. We have thus satisfactory evidence that at an early period of the retreat of the great ice-field covering this continent, when it no longer moved over the highest summits of the land, local glaciers were left in the gorges facing the sea. We have thus traced the glaciated surfaces over the whole width of the State of Maine,

on the prairies of Illinois or Iowa. One may follow these boulders to the fortieth degree of latitude, beyond which they become more and more rare, while the finer drift alone extends farther south. It is not only, however, by tracking the boulders back to their origin in the North that we ascertain the starting-point of the whole mass; we have another kind of evidence to J this effect, already alluded to in the description of the roches moutonnees. Wherever the natural surface of any hill, having a steep southern slope, is exposed, the marks are always found to be very distinct on the northern side and entirely wanting on the southern one, showing that, as in the case of many of the roches moutonnees in Switzerland, the mass moved up the northern slope, forcing its way against it, grinding and furrowing the northern face of the hill as it moved over it, but bridging the opposite side in its descent without coming into contact with it. This is true, not only of hills, but of much slighter obstacles which presented themselves in the path of the ice. Even pebbles imbedded in masses of pudding-stone, but rising sometimes above the level of the general surface, often have their northern side polished and scratched, while the southern one remains untouched. Moraines are not wanting to complete the chain of evidence respecting the ancient existence of glaciers in this country, although we cannot expect to find them here so frequently as in Europe, where the many local glaciers in circumscribed valleys afforded special facilities for the building up of these lateral and transverse walls. Over the broad expanse of the United States, on the contrary, with such slight variations of level, the disappearance of the ice at its breaking-up would naturally be more complete and continuous than in a country intersected by frequent mountain-chains, where the ice would linger in the higher valleys long after it had disappeared from the plains below. Yet it is evident that here also in certain localities the boundary line of the ice underwent oscillations, pausing here and there long enough to collect mounds of the same character as those spanning the valleys of Switzerland and Great Britain. We have several of these mounds in our immediate vicinity. The Waverley Oaks, so well known to all lovers of fine trees in our community, stand on an ancient

being of a softer quality than the granitic rock which it intersects, it has been cut to a little lower level, and the vertical walls of the fissure are polished, scratched, and grooved in the same way. I met here with one of those incidents showing the character of the working-class in America which always strikes a European with astonishment. There was a blacksmith's shop near this dike, and being extremely anxious to obtain a specimen from it on account of the clearness of its glacial characters, I requested the head workman, who had been watching my observations with a good deal of interest, to break me off a piece. It was not an easy task, for there were no angles, the dike being sunk below the surrounding surface and perfectly smooth. After a time, and not without some hard work, a wedge was driven in, and with the help of a crow-bar two or three very satisfactory specimens were pried out. I naturally wished to pay the man for his labor; but he refused to take anything, saying that he saw I was a geologist travelling for the sake of investigation. He added, that he subscribed for one or two papers and magazines: perhaps he should meet with some of the published results of my journey one of these days, and that would be the best reward for the little help he had given. Seeing his interest in the object of my researches, I explained to him the significance of this dike, showed him the direction of the marks pointing straight to the north, and evidently entirely independent of tidal action, since they ran at right angles with it. As I bade him good by, he said, "Henceforth this dike shall be my compass; I shall know when the wind blows due north." The locality was, indeed, especially interesting from several points of view. It is one of the few instances I have seen in which a dike, being composed of a softer paste than the adjoining rock, has yielded more readily to the ice-plough, and is cut to a lower level, thus forming a broad, flat a furrow, the upright walls of which are scored as deeply as the horizontal surface of the dike. Another most important fact is, that the tide daily flows across these marks. Evidently, then, they have not been made by water, since water has no power to erase them, or to obscure them by other lines of the same kind. A mile and a half to the south of Bass Harbor there is a ledge facing north, on which the glacial

the characteristic composition of glacier-drift, and nowhere that of an aqueous stratified deposit, except when afterwards remodelled by the action of water. But of this stratified drift I shall have occasion to speak more in detail hereafter. There is, however, one circumstance, of frequent occurrence, along our New England shores, requiring special explanation, because it is generally misunderstood. Along our sea-shore, and even within the harbor of Boston, at the base of the harbor-islands, as well as the outlet of our larger Atlantic streams, numbers of boulders are found of considerable size; and this fact is often adduced as showing the power of water to transport massive fragments of rock to great distances, the mineralogical character of these boulders being frequently such as to show that they cannot have originated in the neighborhood of their present resting-places. But a careful examination of the surrounding country, and a comparison of the nature and level of the drift on the mainland with those of the same deposits on the harbor-islands, suggest a different explanation of these phenomena. The sheet of drift was once more continuous and extensive than it is now, and the localities in which we find these crops of boulders are spots where the tide has eaten into the drift, wearing away the finer materials, or the paste in which the larger fragments were imbedded, and allowing them to fall to the bottom, or where the same result has been produced by the action of rivers cutting their way through the drift, and thus finding an outlet to the sea. In short, instead of showing the power of currents to carry along heavy fragments, these stranded boulders prove, on the contrary, the inability of water to produce any such effect, since it is evident that the tides washing against the shore, or the rivers rushing down to the sea, were equally incapable of bearing off the weightier materials, and allowed them to drop to the bottom, while they readily swept away the lighter ones. Such localities compare with the surrounding drift much as the bottom of a gravel-pit which has been partially worked compares with its banks. Look into any gravel-pit, a portion of which has already been carted away. At its bottom a number of larger stones and boulders are usually lying, too heavy for the cart, and therefore left upon the spot. Fragments of the same size and character, and

inequalities will make little impression upon the onward movement of the whole mass; but in proportion as the ice wanes, it adapts itself to the depressions and knolls of the surface, in consequence of which the glacial marks lose the uniformity of their trend. The morning following my arrival at Bar Harbor I spent in examining the glacial phenomena in its immediate neighborhood. At Bar Harbor itself, the marks- bear north and north-northwest. A mile farther south they are all in a north-northwesterly direction. The cove of the Spouting-Horn, however, a deep recess in the rock, where the surf acts with wonderful force, -is engraved on both sides with lines running due north. On the same side of the island, considerably to the south of Bar Harbor, there is a striking sea-wall composed of coarse materials, thrown up in a line along the shore, formed, no doubt, by some unusually severe storm, coinciding with high-water. It resembles the well-known sea-wall of Chelsea Beach. Behind this wall stretches an extensive marsh, formerly a part of the sea. Somewhat beyond it, on the shore, are two very distinct polished and grooved surfaces, with the lines running due north. On the afternoon of the same day, I ascended Green Mountain. Along the lower part of the road the marks run northwest, then north-northwest, converging more and more toward their normal course, until, after passing the first summit, and thence upward, they lose entirely the slanting direction impressed upon them by the deflection of the ice about French- man's Bay, and run due north again. All the way up the last slope of the mountain, wherever the rock is exposed, may be see well-engraved flat surfaces of rose-colored protogine, on which the scratches and grooves sometimes run for twenty feet without any perceptible interruption. On the very summit is a quartz dike, cut to the same level with the general outline of the knoll, on which the marks are very distinct. I arrived on the extreme point- where the southern descent is so abrupt that the mountain seems to plunge into the ocean; -just at sunset. The sea as far as the eye could reach was still glowing with color; amethyst clouds floated over the numerous Islands to the southwest; while on the other side in the gathering shadows lay the little lake midway on the mountain slope, and, below, the many inlets, coves, and islands

same phenomena may be produced over level, open I countries. I believe that circumstances similar to those determining the more rapid advance of the glaciers from higher to lower levels at that point where the alternate thawing and freezing, the infiltration of water and consequent expansion of the ice under frost, are greatest, would also determine the motion of a large body of ice from north to south, since it would be along its southern limits that these conditions would prevail; while the great reservoir of snow at the north would correspond to the upper troughs of the present glaciers, from which their lower ranges are constantly fed. The change of snow into ice is owing to alternation of temperature, to partial melting and subsequent freezing, constantly renewed,- and also to the sinking of the mass upon itself in consequence of its own weight, the lower portions being thus forced out by the pressure of the superincumbent ice. Upon an inclined plane the movement consequent upon these changes will of course be downward; but what would be the result, if a field of snow many thousand feet thick, corresponding, except in its greater bulk, to the accumulations by which the present glaciers are caused, were stretched over an extensive level surface? The moisture from the upper superficial layers would permeate the larger mass as it now does the smaller one, trickling down into its lower portions, while the pressure from above would render the bottom hard and compact, changing it gradually into ice. If this should take place under climatic conditions which would keep the whole as a mass in a frozen state, the pressure from above would force out the lower ice in every direction beyond its original circumscription, thus enlarging the area covered by it, while the whole would subside in its bulk. Let us for a moment assume that such an accumulation of snow takes place around the northern and southern poles, stretching thence over the northern and southern hemispheres to latitude forty, and that this field of snow acquires a thickness of from twelve to fifteen thousand feet. Such a mass would subside upon itself in consequence of its own weight; it would be transformed into ice with a greater or less rapidity and completeness, according to the latitude determining the surrounding climatic Influences and the amount of moisture

north, pushed up and over the face presented to it, while the southern face was comparatively protected, the rigid mass no doubt often ill bridging the opposite declivity without even touching it. I suppose these facts, which perhaps seem insignificant in themselves, must be far less expressive to the general observer than to one who has seen this whole set of phenomena in active operation. To me they have been for many years so familiar in the Alpine valleys, and their aspect in those regions is so identical with the facts above described, that, paradoxical as the statement may seem, the presence of the ice is now an unimportant element to me in the study of glacial phenomena. It is no more essential to the investigator who has once seen its connection with the facts, than is the flesh which once clothed it to the anatomist who studies the skeleton of a fossil animal. In the face of these facts it seems preposterous to assume that the loose materials and boulders scattered over this interval should have been stranded by icebergs driven inward from the sea-shore by currents or tidal waves. The whole movement, whatever its cause, was unquestionably in the opposite direction. The testimony of the loose materials and erratic boulders is the same all over the United States. They are always of northern birth. I have never seen a single fragment of rock from any more southern locality resting upon glaciated surfaces to the north of them, though I have searched for them from the Atlantic coast to Iowa. The picturesque island of Mount Desert lies on the southern shore of Maine, in Hancock County, and is separated from the mainland by a narrow arm of the sea. Much higher in the centre than on the margin, its mountains seem, as one draws near, to rise abruptly from the sea. It is cleft through the middle by a deep fiord, known as Somes's Sound, dividing the southern half of the island into two unequal portions; and its shores are indented by countless bays and coves, which add greatly to its beauty. We entered the island on the northwestern side, from Trenton, and proceeded at once to Bar Harbor, on the eastern side. This is a favorite resort in summer on account of its broken, varied shore, and of the neighborhood of Green Mountain, with its magnificent view from the summit and its exquisite lake, sunk in a cup-like

Sweden, Scotland, England, and Ireland were covered by sheets of Ice many thousand feet in height, the ice-fields of Greenland must have shared in the same climatic influences, and have been much thicker and far more extensive than they are at present? Notwithstanding the absence of lofty mountain-chains in America, we are not wholly without the means of measuring the thickness of the ice-sheet, by comparing it, as in Europe, with some of our highest elevations. The slopes of the Alleghany range, wherever they have been examined, are glacier-worn to the very top, with the exception of a few points; but these points are sufficient to give us data for the comparison. Mount Washington, for instance, is over six thousand feet high, and the rough, unpolished surface of its summit, covered with loose fragments, just below the level of which glacier-marks come to an end, tells us that it lifted its head alone above the desolate waste of ice and snow. In this region, then, the thickness of the sheet cannot have been much less than six thousand feet, and this is in keeping with the same kind of evidence in other parts of the country; for, wherever the mountains are much below six thousand feet, the ice seems to have passed directly over them, while the few peaks rising to that height are left untouched. And while we can thus sink our plummet from the summit to the base of Mount Washington and measure the thickness of the mass of ice, we have a no less accurate indication of its extension in the undulating line marking the southern termination of the drift. I have shown that the moraines mark the oscillations of the glaciers in Europe. Where such accumulations of loose materials took place at its terminus, there we know the glacier must have held its ground long enough to allow time for the collection of these debris. In the same way we may trace the southern border of our ancient ice-sheet on this continent by the limit of the boulders; beyond that line it evidently did not advance as a solid mass, since it ceased to transport the heavier materials. But as soon as the outskirts of the ice began to yield and to flow off as water, the lighter portions of the drift were swept onward; and hence we find a sheet of finer drift-deposit, sand and gravel more or less distinctly stratified, carried to greater or less distances, and fading into the Southern States, where it mingles

the extent over which the same set of phenomena may be traced forms an important part of the inquiry, I may indicate a few other points at which similar appearances occur. On the summit of the hill half-way between Brownville and Milo, near the Sebec River, the scratches and furrows are distinctly seen trending due north and south. They recur, after crossing the ferry, on the brow of another hill farther to the south. Between Orneville and North Bradford there are extensive flats, on which the rocks, wherever they are not decomposed, exhibit even and polished surfaces traversed by rectilinear grooves and furrows trending mainly from north to south, though here and there diverging to the west, and even forming occasionally an angle of from twenty to twenty-five ; degrees with the main set of lines. Farther south, as the land begins to rise again, all the marks point once more uniformly northward. To the north and south of the town of Hudson, and especially near the post-office, the scratches are very distinct, bearing due north across slaty rocks, which trend east-northeast. The views from the high lands over all this region are very beautiful. O'Lammon, the Peaked Mountains, and the Union River Mountains limit the horizon in the east; Dix's Mountain rises in the distance on the west; while the Katahdin Mountains are still visible far to the north. On returning to Bangor, I proceeded at once, according to my original intention, to Mount Desert; but before giving an account of the glacial phenomena on that island, I must say a few words of the physical features of the country between Bangor and the sea. This region is intersected by three distinct ranges of hills, without counting the low range between Brewer and Holden. The first divides the valley of the Penobscot from that of Union River, passing through the townships of Clifton, Holden, and Dedham; the second separates the valley of the Union River from the Coast Range; the third is the Coast Range itself, of which Mount Desert and the elevated islands on either side of it form a part; for all these islands, so broken and picturesque in their outlines, must be looked upon as the higher summits of a partly submerged mountainous ridge. These chains do not run exactly parallel with the coast, their trend being more to the north than that of the shore itself; so that the ridges extending

rounded masses in one as in the other. The facts, however, are as I have stated them, and the difference may be due partly to the broken character of the ground over which the drift must have passed in Europe, subjecting it to a more violent process of friction and grinding than in America, and partly to the use that has been made of the drift-boulders during so many centuries for building purposes in the Old World, the drift-boulders being naturally taken first, because they are more easily reached, while the angular ones are frequently perched on almost inaccessible spots. Indeed, the stone fences in both countries tell us the use to which many of the rounded boulders have been put, and the ground in many parts of the United States has already been cleared to a great extent of its rocky fragments for this and like purposes. In the course of time they will, no doubt, disappear from the surface of this country, as they have done from that of Europe.

GLACIAL PHENOMENA IN MAINE

THREE or four years ago I began a series of papers in the "Atlantic Monthly," which, though they appeared as separate geological sketches, had, nevertheless, a certain sequence. These contributions have been unavoidably interrupted for more than two years; and, in taking up the thread again, my readers will excuse me if, by a rapid review of the subject then under discussion, I recall to them the point at which we parted. There were two sets of facts which first awakened the attention of geologists to the ancient extension of glaciers, though at first no investigator connected them with the agency of ice. The first was the presence of boulders in Central Europe and England, which had their birth-place far to the north of their actual position; the second was the presence of similar detached boulders scattered over the plain of Switzerland, and on the slopes of the Jura, which, on the contrary, had travelled from the south northward,

likely to have remained longer upon the higher ground, and when the lower tracks were inundated by the melting of the general sheet of ice, the water, as it rose, may have floated off the remaining bergs, and drifted them across the normal primary scratches bearing due north. On our return from the Katahdin Iron Works our road lay through Brownville, Orneville, Bradford, Hudson, and then along the shore of Pushaw Lake, to Bangor. Through- out this whole tract scratched and polished surfaces and roches moutonnees are frequent. But the most instructive localities of all, in reference to glacial phenomena, are to be found near the slate quarries of Brownville. Here again, as in the roches moutonnees at .Pushaw Lake, the marks run at right angles with the trend and dip of the beds. To explain fully the significance of the facts in this region, I must say something of its general formation. Pleasant River runs through a wide, open valley, the direction of which is very nearly from north to south. The finely laminated clay beds in which the slate quarries are excavated are lifted to an angle of seventy degrees and more, that is, standing almost vertically; and their trend is across the valley east to west, at right angles with it. More favorable circumstances for the study of glacial erosion could hardly be found. On comparing the marks and polished surfaces lich pass at right angles over the edges of these upturned slate beds in the bottom of the valley as well as upon its sides, they are found have exactly the same direction due north as the valley itself. Evidently, then, the agent which produced them must have been instrumental in shaping this trough, as it moved down the valley, before it could follow its path unimpeded by any inequalities of surface. ad it been a fluid mass, it would have fitted self to the lay of the land: it would have followed the vertical edges of the strata, working its way in between them, instead of cutting them all to one evenly rounded surface, as it has done. Indeed, it would seem as if this lace were meant to facilitate the task of the investigator. It presents the data for an immediate comparison between the action of water and that of ice, the limit of the former being distinctly visible in the narrow furrow at the bottom of the valley in which the river has cut its bed. This furrow is sunk somewhat below the general undulating

and coming into sharp contact with the rocks beneath; the accumulation of loose materials pushed along by the advancing ice, or carried on its edges, and forming ridges or walls at its terminus and on its sides. The study of these combined results of glacial action now became part of the subject, and were sought for by geologists wherever the erratic phenomena were investigated. Out of these comparisons has gradually grown a belief that, as the Alpine glaciers were formerly more extensive, so did the northern ice-fields, now confined to the Arctic regions, once stretch farther south. I suppose there are few geologists now who would not readily give their assent to the glacial theory, expressed in this general form. But while the wider distribution of glacial phenomena from mountainous centres in ancient times is now generally admitted, the theory in its more universal application, involving, that is, the existence of an ice-sheet many thousands of feet in thickness moving across whole continents, over open, level plains as well as along enclosed valleys, still meets with many opponents, the staunchest of whom stand high as geological authorities. If not openly said, it is whispered, that, after all, this great ice-period is a mere fancy, worthy at best of a place among the tales of the Arabian Nights; that no moraines have ever been noticed in North America; and that what has been ascribed to the agency of terrestrial glaciers, upon this continent, is simply the work of icebergs stranding against a coast which has subsequently been raised, so that the boulders first deposited by the floating ice along the shores now lie inland at a great distance from the sea. According to this suggestion all the erratic phenomena in North America, the extensive sheets of drift, the continuous and prominent ridges of drift materials, the larger scattered boulders, the scratched, polished, and grooved surfaces, are the work of floating ice, poured forth, then as now, from the Arctic regions. If this be so, we should expect to find all these so-called traces of glacial action running from the coast inward. Let us see now how this agrees with the facts. I will not recapitulate the substance of my last article on this subject, "The Ice-Period in America." It gave a general summary of the glacial phenomena on this continent, as compared with those of Europe, stating at

of Bangor, and especially near Pushaw Lake, the roches moutonnees are very extensive, and, from their character, particularly instructive. These rolling hills are formed by thin upturned clay-slate beds, standing edgewise, in a vertical position, and striking east-northeast. Scratches, grooves, and furrows of every dimension, sometimes very distinct, sometimes fainter, but always rectilinear and always running due north, traverse the edges of these beds at right angles with the surfaces of stratification and the trend of the beds. It is evident that here there can be no confounding of the glacial marks with structural lines, or cracks in the strata, -for these would not run at right angles with the structure of the rock itself; or with furrows made by water, -for these would have followed the strata instead of crossing them; or with any displacement of the beds moving upon one another, -a suggestion which has sometimes been made to explain the appearance of these marks upon horizontal surfaces. Nor is there any trace of the angular ledges which must have resulted from the tilting of these stratified rocks. The whole region is levelled and smoothed down to an undulating plain. While investigating the facts in this locality, I could not but recall the criticism of the "greatest geologist of the age".² upon the glacial theory, then in its infancy; and the ridicule thrown upon the idea that the polished and scratched rocks of the valley of Hasli had been fashioned by ice. He considered these appearances as the natural effects of the shrinking of melted masses under the process of cooling, which might produce some displacement or movement of successive layers one upon another, leading to marks of different kinds belonging to the structure of the rock itself, and not due to any external action. Had the strata in this instance been vertical . in their position, like those of which the roches moutonnees on Pushaw Lake consist, instead of slanting but slightly, like those of the valley of Hasli, such an interpretation could not have been admitted for a moment, and the doctrine of a former greater extension of glaciers would perhaps have been recognized twenty-five years- earlier by scientific men. From Bangor eastward to Eastport, I have made but a hasty survey, -not in the present journey, which included only the country between the Katahdin Iron Works and

change of color, which is as constant as any other botanical character (each kind of tree having its special tints peculiar to itself, and not reproduced by other kinds), may not be amiss. Indeed, not only does every species have its appointed range of color, but each individual tree has its history told more or less distinctly in the ripening of the foliage. A weaker or a younger limb may have put on its autumn garb, and be almost ready to drop its leaves, while the rest of the tree is untouched. A single scarlet maple red oak often gives us the most beautiful arrangement of tints, from the green of mid. summer, through every shade of orange and red; in the same way one leaf may ripen unequally, its green surface being barred spotted with crimson or gold for days before the whole leaf turns. These differences give ample opportunity for studying the ripening process. In attempting to determine the cause of these changes, it ought not to be forgotten that they occur locally, and also make their appearance on particular trees much earlier than upon others; so early, indeed, as to show clearly the fallacy of the prevalent idea that they are caused by frost. The temperature remains ten or fifteen degrees above the freezing-point for a month and more after a good many of our trees have assumed their bright autumnal hues. The process is, no doubt, akin to that of ripening in fruits; especially .in such fleshy fruits as turn from green to yellow, purple, or red, like apples, peaches, plums, cherries, and others. The change in color coincides with changes in the constitutive chemical elements of the plant; and this comparison between the ripening of foliage and fruit seems the more natural, when we remember that fruits are but a modification of leaves, assuming higher functions and special adaptations in the flower, so as to produce what we call a fruit. The ripening process by which the leaves take on their final colors is as constant and special as in the fruits. The cherries do not assume their various shades of red, deepening sometimes into black, or the plums their purples, or the peaches their velvety-rose tints or the apples their greens, russets, browns, and reds, with more unvarying accuracy than the different kinds of maples and oaks, or the beeches, birches, and ashes, take on their characteristic tints. The inequality of the

previously formed. I therefore infer that the local phenomena were the latest in time, and consequent upon the shrinking of the larger continuous ice-sheet. It is' my belief that the ice-period set in, as our winters now do,- only upon a gigantic scale,- by snow-falls, and that it faded as do winters, leaving local patches of ice wherever the temperature was favorable to their preservation. I may say, without exaggeration, that glacial phenomena extend over the whole length and breadth of the State of Maine, wherever : there is no obvious cause for their disappearance. One word of explanation, that this assertion of their omnipresence may not seem overdrawn to those who follow me over the same ground, expecting, perhaps, to find the glacial writing at every step along the road-side, and to see the polished surfaces as shining and slippery as a metallic plate or a marble slab. In the first place, all kinds of rock do not admit the same degree of polish. Coarse and friable sandstone cannot be polished under any circumstances. Only the finer granitic rocks retain the striae and the polished surfaces very distinctly, in this region; and even upon these they are frequently hidden by the accumulation of soil, or occasionally obliterated by decay, where the rock is not hard enough to resist the atmospheric influences. The loose materials themselves, which have served as emery to grind down, polish, and groove the surface of the soil, may eventually become a screen to cover it from observation. The skill of the geologist consists in tracing these Marks from spot to spot over surfaces where they were once continuous. When I say that I followed the glacial marks, compass in hand, from north to south, over a line a hundred miles in length, I do not mean that I never lost sight of them for that distance; but simply that one set of lines, which always ran due north and south, unless deflected as we shall see by some local cause usually explicable, on the spot, might be traced at intervals over all the rocky surfaces. If they disappeared under a stream on its northern shore, they reappeared on the southern side; if hidden for a time by some mass of vegetation, they were found again farther on; and thus-allowing for natural and inevitable interruptions -it may be correctly said that they are continuous over the whole country. The glaciated surfaces -to express in one word the combined

pebbles, while moraines are built chiefly of angular fragments of rocks. Neither can they have been accumulated by currents of water; for they occur in positions where any flood passing over the country, far from producing such an arrangement, must have swept them away, or at least have scattered them and destroyed their ridge-like character. They are, indeed, identical with the bottom glacial drift, that is, with the materials collected beneath the present glaciers, and ground to a homogeneous paste by their pressure and onward movement. I would call such accumulations ground moraines, that is, moraines formed completely under the glacier, and resting immediately upon the rock or soil beneath. Of course, masses of drift below a great sheet of ice, moving steadily in the same direction over uneven, rocky surfaces, cannot preserve the same thickness throughout. Here and there the incumbent weight will press more heavily in one direction than in another, thus crowding the loose materials together, rolling them into ridges following mainly the direction of the movement. Occasionally such uneven pressure may drive these materials up from either side, along the summit of a rocky ledge, or heap them at any height upon its slope. We have seen that the horsebacks, though uneven and winding, usually run from north to south; but occasionally also they trend from east to west. This is the case where a morainic accumulation of loose materials may have been pushed forward, along the margin, in front of an extensive sheet of ice moving southward, and then left unchanged by the subsequent retreat northward of the whole mass. I conceive that such horsebacks, running east and west, may be compared to terminal moraines, which, as is well known, owe their origin to oscillations of the front end of a glacier, pushing forward a mass of loose materials, thus throwing it up into a transverse ridge, and then melting away to some point farther back. I have already shown, in previous articles, how such walls are constructed, often forming concentric ridges one within another, each of which marks a retreating step of the glacier. Sometimes the summit of the horsebacks is so broad and even that the country people consider them as natural roads, and build their highways along them. They are indeed occasionally so symmetrical that they have been taken for artificial Indian