lead to the supposition that this means of transit will ever be very much extended. Where practicable, river navigation appears to be extensively used, and the success or otherwise of the works at present under construction with the view of opening up the navigation of the Godavery, will probably determine whether or not similar operations shall be carried out on other rivers. There is also no doubt that by the introduction of an improved class of steamers many rivers might successfully be navigated, which contain too small a depth of water for the majority of the vessels hitherto in use; three such steamers, calculated to draw only 12 inches of water, are now in course of construction for the river Godavery. Should they prove successful on that river, it is not unlikely that they will be followed by others on the same plan for employment on various streams hitherto not navigated by steam, and on which only vessels of very shallow draught could be employed. With respect to railways, it is not probable that any very great extension of the present system of high-cost lines will be sanctioned, except where they may appear necessary for political or military purposes, and we look rather to a development of the principle of light railways, which may readily be laid down along existing lines of road, and ultimately perhaps, when the traffic has become sufficient to justify the expense in a commercial sense, they might be completed substantially so as to unite with the existing system of high-speed railways, just as it is customary to make a fair-weather road in the first place, and afterwards complete it, by bridging and metalling, as a first-class road.

IV. ICE MARKS IN NORTH WALES.

(With a Sketch of Glacial Theories and Controversies.)

By Alfred R. Wallace, F.R.G.S., F.Z.S., &c.

One of the most interesting branches of modern geology, and that on which recent researches have thrown most light, is the inquiry into the exact modes by which the present surface of the earth has been produced. When we see a vertical precipice, a deep chasm, or huge masses of shattered rock, our first impression is to impute these effects to some violent convulsions of nature, such as volcanic eruptions, earthquakes, or floods. It is, however, now generally admitted that such causes have had, for the most part, little if any effect in modifying the surface, except when many times repeated during long periods of time; and it is every day

becoming more certain that even the grandest and most romantic scenery of mountainous countries has been produced by the slow but long-continued action of those natural causes which we see daily at work, but whose effects during the few years that we can observe them are almost imperceptible. These causes are, the ocean waves, running water, rain and frost; which, if acting for long periods during which subterranean forces are also at work slowly elevating and depressing large tracts of country and to some extent fracturing and loosening the rocky strata, seem capable of producing all the chief features which the surface of the earth now presents in non-volcanic regions.

There are, however, a considerable number of very remarkable phenomena which none of these causes will account for, and which appear to have been overlooked or thought unimportant till about twenty-five years ago, when the celebrated naturalist Agassiz visited this country after having carefully studied the effects of modern glaciers in the Alps. He it was who first showed that they could be all explained to the minutest detail by the hypothesis of a recent "glacial period," during the continuance of which the mountains of Wales, Cumberland, and Scotland were covered with perpetual snow, and sent down glaciers into most of the valleys, and sometimes even into the sea. At first this hypothesis was received with incredulity and derision, since it completely contradicted the almost universal belief of scientific men that the earth had been for ages cooling, and that all preceding epochs had been warmer than the present one; but it very soon worked its way even among the most sceptical inquirers, till at the present day there cannot be found a geologist who denies the reality of the "glacial epoch," or the correctness of that interpretation which explains many peculiar features of our own mountain scenery by the agency of ice.

A great deal has since been written by geologists and physicists on the effects of ice-work, but comparatively little has been given to the general public; and as the subject is at this time again attracting much attention, owing to new applications of the theory which have given rise to much discussion and are greatly stimulating inquiry, and as it requires little or no previous knowledge of geology to understand either its facts or its theory, I have thought that a popular account of such prominent glacial phenomena as are observable in all our chief mountain districts would be acceptable to many readers of this periodical.

We may conveniently consider the chief evidences of a glacial period under the following heads: 1st, The drift; 2nd, Moraines; 3rd, 'Roches moutonnées'; 4th, Grooved and striated rocks; 5th, Boulders and perched blocks; 6th, Alpine lakes;—and in this order I propose to record the few observations I have made during a month spent near Snowdon and Cader Idris last autumn, incorpo-

rating briefly what has been observed elsewhere, and adding some account of the more interesting problems and discussions to which they have given rise.

1st. The Glacial or Northern Drift.—This is a layer of loose materials—gravel, clay, mud, pebbles, and angular stones—which is found spread at intervals all over Northern Europe, and is very common in the valleys and upland slopes of North Wales. It is very abundant all round the town of Dolgelly, where it forms undulating slopes, mounds, and hummocks in most of the valleys, filling up the space between the flat alluvial meadows on the river side, and the steep rocky slopes of the adjacent mountains. Wherever this is cut through in making roads or railways, it is seen to be full of blocks of stone, pebbles, and large masses of rock, distributed through it without any order or arrangement, the top, middle, and bottom being alike in composition. From the contour of the surrounding mountains it can be often seen that this deposit is of great though very variable thickness, probably often exceeding a hundred feet, and it certainly covers many hundred square miles of country in North Wales alone. On ascending the mountains it is often found on their less precipitous slopes and in the upland valleys, at more than a thousand feet elevation; and it has even been traced around Snowdon by Professor Ramsay to a height of more than two thousand feet. The materials of which the drift is composed are various. Sometimes the rocks are nearly all those of the surrounding mountains, at other times they are such as must have been brought from a great distance. The geological age of the drift is determined by its overlying all, even the most recent formations, and by its containing occasionally marine shells of an arctic type and of species which are all now living.

Here we have materials of a loose and miscellaneous nature which were deposited *in* the sea but not *by* the sea. That the drift was deposited in the sea is proved by the marine shells which have been found in it up to the height of 1,300 feet on some mountains of Carnarvonshire; and we have thus a proof that North Wales was at a very recent epoch sunk to at least that depth beneath the ocean. The presence of the drift itself, however, at a height of more than 2,000 feet, would prove a much greater submergence. That the deposit could not have been made by the sea, is shown by the want of arrangement of the materials and the abundance of large angular fragments of rock. Water always sorts the materials it deposits. The rocks, the pebbles, the shingle, the sand, the mud, are carried different distances, and deposited in different places or in different layers. Water deposits are stratified. Neither can rocks be carried far by water and retain their angles and clean fractured surfaces. They get rounded into boulders or

pebbles, whereas many of the rocks and stones found in the drift are as sharp, angular, and irregular as the blocks and masses which are detached by the winter's frost, and lie under an inland precipice.

The solution of this curious problem of the origin of the drift, is to be found in the history of glaciers and icebergs. When a valley is filled with ice, the rocky *débris* from its slopes and precipices fall upon the surface of the glacier. A quantity of the earth and stones of the bottom of the valley is also forced into the crevices or frozen to the bottom of the icy mass. Now when the ice-filled valley terminates in the sea, large fragments of the glacier break off and become icebergs, and floating away carry with them their load of earth and rocks, which are deposited where they melt, or topple over, or are stranded. In the North Atlantic as far as icebergs float, there must be an annual deposit of matter on its bottom exactly of the same nature as the drift, while in Hudson's Bay and the Gulf of St. Lawrence it must be accumulating still more rapidly. When North Wales was one or two thousand feet lower than at present, it must have formed a group of islands, among which icebergs would frequently become entangled and deposit their loads of foreign matter. At the same time Snowdon and Cader Idris would have been sending down glaciers into the sea, which would spread the *débris* of their precipices and valley bottoms on what are now the upland slopes and low valleys, but which then were submerged banks and ocean straits. As the land rose above the sea to its present elevation, rivers, floods, and glaciers would more or less furrow and clear away the drift from the valleys, and leave it distributed in the irregular manner in which we now find it. The mere presence, therefore, of this unstratified mass of earth, rocks, and boulders would of itself prove a recent glacial period; since it clearly indicates the existence of icebergs and glaciers in seas and countries where they are now never found.

2nd. Moraines.—Every modern glacier carries upon its surface more or less of the *débris* of the rocky valleys through which it passes. As the glacier moves downwards, these are carried with it, and at its termination, where its waste by melting exactly balances its downward progress, this *débris* must necessarily be deposited, and form a more or less regular heap of rock and earth called the terminal moraine. These moraines are sometimes destroyed almost as fast as they are formed by the streams which issue from the glacier itself or by torrents from the adjacent mountains, but under favourable conditions they remain, and long after the glacier has entirely disappeared tell the tale of its former existence. If owing to a steady change of climate a glacier retires regularly, the moraine-heaps will be distributed over the whole surface

its terminal ice-cliff has successively occupied; when on the other hand it is stationary for a considerable time, the *débris* accumulates to some height, and forms a well-defined terminal moraine. Some of the moraines formed by the old Swiss glaciers, when they stretched far down into the plains, are enormous. That of Ivrea in North Italy is many miles in extent, and 1,500 feet high—a mountain of *débris* brought down by a glacier which was sixty miles long. There is no other natural agent which can form on level ground such regular mounds as these moraines, many of which resemble artificial earthworks. Their presence becomes therefore a very certain indication of the former existence of glaciers.

In North Wales many very perfect moraines may be observed. Around Snowdon in particular they are very abundant, every one of the valleys which radiate from the central peak of the mountain exhibiting them more or less distinctly. These are all described in Professor Ramsay's little work on the Old Glaciers of Switzerland and North Wales; and I can bear witness that, far from exaggerating, he has hardly dwelt sufficiently on the wonderful clearness and well-marked character of this phenomenon. The most striking of all are perhaps those of the Cwm Glass Valley, which descends from the north of Snowdon to the pass of Llanberis. At the mouth of this valley, close above the road which ascends the pass, is what seems to the passer-by a steep rocky hill, but on viewing it from an elevation about a quarter of a mile lower down, it is seen to be a huge longitudinal roof-shaped mound of almost perfect regularity, scattered over with angular blocks of rock; and whose position, with regard to the sides and bottom of the valley, shows it to be an addition—something put there—and having no relation to the proper contours of the surface. Higher up the valley is a small but wonderfully perfect moraine, which stretches across in a regular curve, and of almost uniform size and height, so that when standing on it one can hardly help believing it to be an artificial fortification. But the huge angular blocks of rocks scattered about it, and the other signs of ice-work all around, with the wild loneliness of the situation, and its inferiority as a defensive position to many other points near it, utterly forbid this supposition. The best example of the wide-spreading of rocky *débris* by the gradual retreat of a glacier, is to be seen in Cwm Brwynog. Under one of the blackest precipices of Snowdon lies the little green lake Llyn dur Arddu, on the other side of which rises a steep ridge, most likely partly rock and partly moraine. Beyond this ridge extends for nearly a mile a gradually-sloping upland, so thickly covered with blocks of rock, often of large size, that from a distance the herbage can rarely be seen between them. In this case every one of these rocks must have been carried across the valley of the lake and deposited where it now lies, and no other natural agent can be found or imagined

capable of doing this but ice. Lower down this same valley, on the spur which separates it from Llyn dwythwch, are portions of moraines deposited by the glacier when, during its greatest extension, it descended to join that of the vale of Llanberis. The moraines around Cader Idris are not so numerous nor so well marked as those of Snowdon. There is, however, a very fine one circling round Llyn y gader, under the highest peak; and lower down, below Llyn y Gafer, is a rock-strewn slope, even more thickly covered than that of Cwn Brwynog. Llyn Cai, situated in the tremendous chasm on the south of Cader Idris, has also a small but very perfect moraine at its extremity, through an opening in which its waters escape. I believe that the existence of moraines and moraine matter, when as well marked as those of North Wales, is of itself sufficient to prove that there has been a glacial period. There is, however, much other confirmatory evidence.

3rd. Roches Moutonnées.—Glaciers are often many hundred or even several thousand feet thick, and as they move slowly over the surface their enormous weight, assisted by the gravel, pebbles, and boulders frozen or imbedded in them, grinds down all sharp angles, peaks, and jagged edges of the rocks, giving to them a more or less blunted or rounded outline. The degree to which this grinding away takes place must depend on many causes, such as the weight of the glacier, its rate of motion, the material it carries with it, the time it continues in action, and the hardness, toughness, and original form of the rock itself. This peculiar effect of the passage of a glacier is very easily recognized when once seen, especially if one studies the forms that the rock assumes by natural weathering or by the action of water, both of which will be seen to be very different from that produced by ice. In the valleys around Snowdon and Cader Idris this form of rock-surface is continually to be seen, and when, as is frequently the case, the comparatively soft, slaty rocks can be compared side by side with hard greenstone or grit, the first is found to be ground down to a smooth surface, gently curved or rounded, while the second is left in irregular bosses and lumps, all their asperities smoothed and rounded off, but not ground down to an even surface. This can be well seen on the banks of Llyn Padarn, near Llanberis. It is upon these *roches moutonnées* that are often found the peculiar markings we have next to consider.

4th. Grooved and Striated Rocks.—During the process just described, it frequently happens that grooves or scratches are made upon the rocks by the hard materials imbedded in the bottom or sides of the glacier. Owing to the enormous weight and slow motion of glaciers, they move with great steadiness, and thus the markings

on rock-surfaces are almost straight lines parallel to each other, and show the direction in which the glacier moved. Nothing is more striking than to trace for the first time over miles of country these mysterious lines, ruled upon the hardest rocks, and always pointing in the same direction. In the neighbourhood of Llanberis they are so abundant, that it seems strange they were not observed, compared, and speculated on long before their true nature was known. The lines vary from fine scratches to grooves in which one's finger may lie, and even to troughs a foot or more in diameter. Sometimes on very hard rock the grooves are polished by the intense pressure of a hard smooth pebble. On the east side of Llyn y gader is an even slope of near a thousand feet at an angle of about 45° called the Fox's Path, and covered with loose fragments of rock which roll away under one's feet at every step. It descends from a saddle between two eminences of Cader Idris, and was probably long the path of avalanches or small glaciers. In the bed of a torrent which descends this slope I found, recently exposed, a large piece of yellowish porphyry, one surface of which (about 5 in. by 3 in.) was slightly ridged and furrowed, and highly polished. The rock is very heavy and excessively hard, and this fragment is of itself a striking proof both of the presence of ice and of its power as a grinding and polishing agent. I presume that the piece formed part of the rocky bed over which the ice once slid, that it had been split and loosened by atmospheric action and then covered up and preserved by sediment and stones, till the torrent exposed it again, and would soon have destroyed its polished surface had I not been lucky enough to hit upon it.

But it is not only the surface of rocks *in situ* that are thus marked. The pebbles, boulders, and fragments embedded in the glacier are themselves equally scratched, but as they are capable of shifting their position the grooves and striæ on them are not always parallel to each other. It is this kind of material that contributes largely to form the drift, and in some localities almost every boulder and pebble is more or less marked. On close examination we can often find proof that the grooves are really ancient markings by their correspondence in appearance with old surfaces of the stone, although this is sufficiently evident to anyone who sees their number, and the variety of rude masses which bear them. These various classes of markings are all found abundantly wherever glaciers now exist, and as no other mode of explaining their occurrence has ever been suggested, they may be considered to form the best and most convincing of all the various proofs of the former existence of glaciers and icebergs in places where they are not now found.

5th. Boulders and Perched Blocks.—As a glacier in its passage down a valley covers many irregularities of ground, some-

times passing over lateral spurs or rocky eminences, so during its retreat the ice-cliff which terminates it will pass over each of these in succession, and will deposit on many of them some of the blocks which form its moraines or the boulders it has brought down with it. When the glacier has finally retreated, many of these blocks and boulders will remain in positions where neither simple gravitation nor the action of floods of water, nor the shocks of earthquakes could have placed them. Very similar phenomena have been produced by the icebergs which deposited the drift, large masses of rock having been carried and dropped on eminences as well as in valleys. Not unfrequently these blocks rest upon rock of a different kind from that of which they are themselves composed, and they often rest on ice-worn surfaces marked by grooves and scratches, showing plainly that the face of the country has undergone little or no change since the ice left it. Many of them occur on the edge of precipices and ravines, as is particularly the case at the torrent walk near Dolgelly, the sides of which on nearly level ground are thickly strewn with large angular blocks and boulders. One of these is 15 feet square and 9 feet high, and has lower ground all around it. It is when they stand upon the summit of conspicuous eminences, as they often do about Snowdon and Cader Idris, that they attract most attention, while when thickly strewn over level ground or on slight hillocks and ridges they are passed over by the tourist as too common a phenomenon of mountainous countries to deserve attention. Yet it is really as difficult to account for their presence in the one case as in the other, without the agency of ice. Neither do they form a universal feature of mountainous regions, as many suppose, for, as far as my memory serves me, they do not occur on mountains of moderate heights in the tropics. I have ascended many mountains in the Malayan Archipelago about the same height as Snowdon, and on calling to mind all the places where large blocks of rock were scattered about, I cannot remember any that were not at the foot of steep declivities to which they might easily have rolled. I much regret that I was not then aware of the importance of minute observations of the kind. It appears certain, however, that in hot countries and where there is no reason to believe that glaciers have ever existed, this phenomenon of the wide distribution of angular blocks of rock over slight slopes, level ground, and eminences, does not occur, otherwise it would have been brought forward long ago, as a complete disproof of the glacial hypothesis. In South America, however, I did meet with one remarkable perched block, a tabular mass from 20 to 30 feet in diameter supported on two points of rock only, and as far as I can recollect situated on a slight eminence, certainly not under a steep slope from which it could have fallen. Its position was exactly such as might be produced if it had been deposited by a grounded iceberg, but hardly by any other means.

It was about half-a-mile from an isolated granite mountain in lat. 0° 30′ N., long. 68° 50′ W.*

This observation becomes of considerable importance now that Professor Agassiz tells us that he has found plain traces of glacial action in the valley of the Amazon. That glaciers have ever descended from the Andes to the Atlantic ocean, a distance of more than 2,000 miles, will hardly be credited except on such overwhelming evidence as even Professor Agassiz does not pretend exists. There are not, however, the same difficulties in the way of the supposition that icebergs once floated over what is now the great Amazonian plain. A depression of 1,000 feet would sink the whole of that plain deep under the ocean, and that such a depression has occurred is rendered probable by the great extent and almost perfect level of its alluvial deposits. Neither is it unreasonable to suppose that during the glacial epoch of Europe and North America the temperature of South America was so much lowered as to bring the line of perpetual snow down to 12,000 or 13,000 feet. This would cause a wide extent of the plateaux in South Peru and Bolivia to become the feeders of glaciers, which might have been as much larger than those of the Alps, as the comparative height and extent of the two mountain systems would lead us to expect. Such glaciers descending the highly inclined Andean valleys would move with proportionate rapidity, and might not improbably reach down into an almost tropical climate and send off rock-laden icebergs into the warm inland sea that then washed the base of the Andes. This, however, is quite a digression from our present subject.

On the very summit of Cader Idris there are several detached eminences formed of large square and polygonal blocks, which in some places stream down the slopes of the undulating surface of the mountain top. Were they lower down we should at once pronounce them to be moraines, but in their present position they are somewhat difficult to account for. I think, however, there can be little doubt but that they are due to the action of the snow and frost during the last portion of the glacial period. As soon as the perpetual snow line reached the top of the mountain, and the permanent glaciers below had all melted away, there must have been a long period during which the rocks on the summit were subjected to the alternate action of ice, snow, and water. During the winter they would be buried under many feet of snow, which would be forced into every crevice in the form of compact ice. During the short summer the snow would melt from the surface, but the water in the fissures would be probably frozen every night, leading to the further fracture and displacement of the rocks. The pressure of the snow and ice in the succeeding winter would force these always

* See Wallace's 'Tavels in the Amazon and Rio Negro,' p. 219.

a little downward in the direction of least resistance, and this alternate action, combined with the character of the rock, which is here chiefly basaltic and splits into rude tabular and columnar masses, seems sufficient to have produced that mass of blocks heaped confusedly on the very summit of the mountain, which almost always suggests to the mind of the non-geological visitor some tremendous convulsion of nature, and makes him readily accept the popular theory that the vast hollow of Llyn Cai is a volcanic crater.

In the 'Geological Magazine' for September, 1866, Mr. Macintosh maintains that the action of the sea has had most to do with the formation of the valleys, cwms, and rocky surfaces of the Welsh mountains; and he particularly instances Mynydd y Gader, a rounded rocky mountain between Cader Idris and the town of Dolgelly, as offering unmistakable evidence of a "seaworn summit." I therefore devoted an afternoon to an examination of this mountain, and was much surprised to find all over it what appeared to me the most unmistakable evidences of "ice-work." The mountain is composed of greenstone and lower Silurian flags, with veins and masses of quartz. It is very rugged and uneven, consisting of rounded lumps and knolls with numberless hollows and little valleys between them. These are all more or less thickly covered with angular blocks, slabs, and columnar masses, some standing on the very summits of the knolls, others lying on steep slopes; but there is no arrangement of them in lines or layers, there are no water-worn pebbles or boulders, no sand or shingle, nor, as far as I could see, any sign whatever of the action of the sea. On the other hand, the whole mountain offered the finest possible examples of *roches moutonnées*, the smooth slopes always facing Cader Idris, from which the glacier had come. Some of these ice-ground surfaces were as smooth as a pavement although formed on the outcropping edges of the hard Silurian rocks, an effect which the sea *never* produces. There is an angular block containing about twenty cubic yards of stone, standing on the slope of one of the highest bosses of the mountain, with no precipice from which it could have come nearer than Cader Idris, more than a mile off, with a valley between. Owing to the exposed situation of the *roches moutonnées*, their surfaces have been much weathered, and I did not succeed in finding good groovings or scratches, though I have no doubt such could be found by a more careful search. With this exception, the evidences of recent glacial action are seldom to be seen more plainly than upon this mountain.

The phenomena of existing glaciers and icebergs have been now so carefully studied, and the various effects which they produce are for the most part so well known, that there is no longer any

difference of opinion among geologists about referring such phenomena as I have hitherto been considering to the action of ice, even though the countries where they occur no longer produce glaciers. But on the question of the origin of Alpine Lakes, which we have now to consider, there is no such unanimity.

6th. Alpine Lakes.—It is only about five years since Professor Ramsay propounded the startling theory that almost all the lakes which form one of the greatest charms of our mountain districts, were actually produced by that comparatively recent irruption of thick-ribbed ice over a great part of the temperate zone, which we can hardly contemplate without a thrill of horror; and that during the preceding warm tertiary epochs they were so scarce as to form no important feature in the scenery of Europe. A short and simple statement of this theory is as follows. In all districts where glaciers have been proved to exist there are numerous lakes. In exactly similar districts where there is no trace of there having ever been glaciers, there are few or no lakes. This holds good all over the globe. Glaciers wear away their beds, as proved,—first, by the immense quantity of sediment in all glacial streams; secondly, by the existence of "roches moutonnées" wherever glaciers have passed. It can almost always be shown that the old glaciers have passed over the exact spots where the lakes now are, and the size of the lakes bears a general proportion to the proved size of the old glaciers. This theory of the glacial origin of Alpine lakes is now the great battle-ground of physical geologists. In this country Ramsay, Jukes, Geikie, and Tyndall are its chief supporters; Sir Roderick Murchison and Sir Charles Lyell, its chief opponents. Every year brings fresh evidence and new combatants; and as it is a question of such great interest, and at the same time one rather of physical than of purely geological science, I shall endeavour to give such an outline of the subject as may enable the general reader to understand the question at issue and form his own judgment upon it.

The first point to be considered in explaining the origin of lakes, is to form such a theory as shall not only show how such and such particular lakes were or might have been formed, but shall also account for their present actual distribution over the surface of the earth. This may be learnt from good maps as well as by personal observation, and is highly peculiar. In our own island we all know that it is only in three mountainous districts that lakes abound; in Wales, in Scotland, and in Cumberland. The lakes of these districts amount to some hundreds. In Europe the best known lake district is that of the Alps, which contains hundreds of lakes and many of very large size. In the Scandinavian

peninsula lakes are still more numerous, abounding not only in the mountain valleys but also out in the low flat country, which, as well as all Finland and wide districts of North Russia, are literally studded with thousands of lakes. In North America, while the middle and Southern United States have scarcely any lakes, all the North-eastern States, Canada, Nova Scotia, Labrador, and in fact all the northern part of the continent, although much of it is level ground, is absolutely strewn broadcast with lakes, which must number very many thousands of every size, from the great inland seas like Lake Superior down to small tarns and ponds. In British Columbia, Oregon, and North California there are also abundance of lakes. In the great plateau of Asia there are lakes in plenty in Mongolia, in Tartary, and in Thibet, and all along the northern side of the Himalayas. But on going south from all these countries, the lakes in most cases abruptly cease. On carefully examining the best maps of Spain, a country of immense extent and highly diversified both geographically and geologically, I can find not a lake marked upon them. The fine island of Sardinia contains groups of mountains rising to 3,000 and 6,000 feet high. It has a varied geology, presenting abundance of granitic, metamorphic, tertiary, and volcanic rocks, and yet, according to a large Italian Government map, it contains not a single mountain lake. The Atlas range of mountains in North Africa presents us with no lakes. In America, the great West India Islands, Cuba, Jamaica, and Haiti, appear to have no lakes. Further south, the immense empire of Brazil, with its vast mountain ranges, its plains, savannas, and innumerable rivers, is almost destitute of lakes, except a few small ones near the sources of some of its southern rivers. In Asia the immense peninsula of India and the fine island of Ceylon seem to have hardly a true inland lake. In Africa, the Cape district and Natal have plenty of mountains but no lakes. Central, Africa, it is true, has lakes, few in number but of large size. They are not, however, accompanied by the immense number of smaller ones which occur in every one of the before-mentioned "lake-districts," and probably come under a distinct category, as lakes formed by unequal subsidence and upheaval. Australia possesses a few lakes; Van Diemen's Land, several; while in New Zealand they abound, especially in the southern districts where large glaciers still exist, and where there is a true lake-district very similar to that of the European Alps.

Now here we have a most remarkable fact,—*the fact* which must be considered in dealing with this question,—namely, that in all countries and districts of the globe where the universally-admitted evidence of extensive glacial action exists, lakes abound, and form one of the great features of the country; while wherever

there are no signs of ancient glaciers, or no reason to believe that the country has in recent geological times been subjected to the action of ice, these lakes are either very few, or (much more frequently) entirely absent. So vast is the disproportion, that if we leave out such lakes as are near the sea-coast, or in alluvial plains where they may have been easily formed by changes in the course of rivers, and such as in volcanic countries are formed in the craters of old volcanos, it is probable that for every *thousand* lakes that exist in glaciated districts, not *one* can be counted in all the rest of the globe! There is, therefore, a strong *primâ facie* case in favour of a theory which directly connects glaciers and lakes as cause and effect; and the opponents of that theory, if they cannot absolutely prove it to be false in a good many cases, should be prepared with some plausible hypothesis which will equally well explain this prominent fact. Yet, strange to say, I have been unable to find that any such hypothesis has been yet put forth. Professor Ramsay's opponents all confine themselves to pointing out the difficulties of his theory in particular cases. They say that ice cannot travel up a long slope from a depth of more than 2,000 feet; that it would remain immovable at such depths, the upper layers sliding over the lower; that a glacier's power of erosion is very slight; that the ends of some existing glaciers are seen to rest on loose moraine matter without even disturbing it; and other arguments of a similar nature.* These arguments may be good or bad, and Professor Ramsay has answered them all himself

* It appears to have escaped the notice, both of Professor Ramsay and of his opponents, that in the paper which immediatey precedes that on the "Glacial Origin of Lakes" in the Geological Society's Journal of August 1st, 1862, Mr. Jamieson adduces evidence of the very fact which has so repeatedly been denied in reference to Professor Ramsay's theory, namely, *that a glacier can move bodily for a considerable distance up a slope.* Mr. Jamieson states, that from the point where the gorge below Loch Trieg opens into Glen Spean, all the ice-marks indicate that the glacier had parted in two directions, flowing both down the valley to the west, and *up the valley to the east*, along Loch Laggan and over the pass of Makoul into the valley of the Spey. This is proved by the lower side of the rocks being abraded and smoothed above the entrance to Loch Treig, while lower down it is the upper sides that are ice-worn. In Glen Roy also the same thing has occurred, the glacier having moved up it instead of down it, and discharged itself over the water-shed into another valley instead of by what now appears its natural outlet into Glen Spean. A sufficient cause for this extraordinary phenomenon seems to be found in the former immense accumulation of ice in Glen Spean, rising far up above both these low passes, as proved by plain ice-marks to the height of more than 2,000 feet. It would be very important to have an accurate survey made of this district, with all the heights well determined, and a thorough examination of the glacial phenomena it presents. These, as described by Mr. Jamieson, clearly indicate that in two separate cases glaciers about twelve miles long have been forced to move up hill, and to empty themselves over the passes at the heads of their respective valleys; and that in so doing they have abraded the rocks at the sides and bottoms of the valleys, showing that the ice could not have remained stationary below while it was flowing on above.

in the 'Philosophical Magazine.' What I particularly wish to call attention to is the fact, that the only theory put forward even by the most eminent of his opponents is, that the depressions in which lakes lie (when they are bounded by rocky strata and not merely dammed up by moraines) have been formed by unequal disturbances of the crust of the earth or upheavals of valley bottoms, and that the ice during the glacial period may have filled up and slightly modified these basins, and also have prevented them from being silted up, but did not form them. In no one case that I am aware of has it been shown that the strata are thus tilted in opposite directions so as to produce a lake basin, nor is any hint given why these tiltings and depressions should have occurred in the proportion of a thousand times in glaciated districts to once in countries that have not been ice-ground.

The suggestion that lakes, however numerous, formed beyond the limits of the ancient glaciers, may have been all silted up and converted into alluvial plains while those filled by ice have alone been preserved, seems at first sight to meet the case, but a little consideration shows that it is quite inadequate to solve the problem. First, we have no right to start with any other assumption than that lakes before the commencement of the glacial period were distributed with some average regularity over the different regions of the globe, if causes so universal as tiltings and depressions of strata were the chief causes that produced them. Secondly, if the present disproportion in the distribution of lakes was caused by those not preserved by ice being silted up, it would show that the process of filling up lakes is almost always very rapid, and therefore that no lakes can be very old. The ten thousands of existing lakes must therefore all have been originally formed just before the commencement of the glacial epoch, and in a time not so long as has since elapsed; and yet, during the whole time that has since elapsed, the process of lake forming must have entirely ceased over more than one half of the globe! Another, though a minor difficulty, is that it is necessary on this hypothesis to suppose that the time the glacial epoch lasted was many times longer than the time which has elapsed since the ice left the lake basins, for we see that the existing lakes have been only to a very small extent silted up, whereas the supposition is that ninety-nine hundredths of the lakes of all the rest of the world were silted up during that period. I have gone a little into this general argument of distribution, because it is one that a man who knows very little either of geology or glaciers may put forward without presumption, and also because it seems to me to have been very much lost sight of in the discussion of this question. We can all see that a true account of the origin of lakes must explain their present most remarkable distribution,

although very few of us may be able to form any sound judgment as to what angle will stop a glacier's motion up hill.

It would appear, then, that there is at all events a strong case in favour of glaciers having had something to do with the formation of lakes. I therefore examined with much interest into the peculiar arrangement and position of the small lakes of North Wales, to see if they gave any support to Professor Ramsay's theory or seemed inconsistent with it. We may conveniently group most of these lakes into:—1st, such as lie in more or less regular bowl-shaped hollows of the mountains; and 2nd, those situated in longitudinal valleys. Immediately beneath the peak of Snowdon are three great chasms, which contain small lakes at an average elevation of 2,000 feet above the sea. On the east is Glas llyn, on the north are the two small lakes of Cwm glas, and on the west are the three little lakes of Cwm Clogwyn. All these lie in irregularly bowl-shaped valleys with a comparatively narrow opening; they all spread out and are larger within than the entrance to them would lead one to expect. Another feature they have in common is a comparative flatness of bottom. From below you have to climb a steep ascent or even a precipice to reach them, but when you have surmounted this you find a rugged undulating surface spreading out to the foot of the precipices which every where surround it. Cader Idris has two somewhat similar chasms containing lakes, and on carefully examining the Ordnance maps we see that there are numbers of such lakes around the higher mountains, occupying lofty bowl-shaped chasms with a more or less narrow exit. One of the largest of this class of lakes is Llyn Llydaw, which is more than a mile long and lies right across between two spurs of Snowdon, which close round it so as to leave a very narrow entrance. How these valleys were originally formed it is not very easy to understand, unless they can be connected with varying texture and resistance of the rocks. The symmetry of their arrangement around or on each side of lofty mountains is against this supposition, and I have been often inclined to think that they must owe their peculiar form to marine action during the various submergences the country has undergone. However this may be, it is evident that such a form of ground being already in existence when the glacial period came on, the ice must have accumulated in these crater-like hollows to a great height, and pressing forcibly on a nearly flat or undulated bottom while in slow but continued motion outwards, could hardly fail to deepen the basin here and there and thus form the little lakes we now see.

The second class of lakes or those in longitudinal valleys are generally situated at a much lower level, and are as a rule larger than the mountain tarns just described. The two lakes of Llanberis,

together more than three miles long, are good examples of this class, and illustrate very clearly their characteristic peculiarities. There is a drainage into these lakes of about twenty square miles of country, bounded on both sides by mountain ranges over 3,000 feet high. The whole of the glaciers from these had to pass out between the ridge of the Clegr and that which descends from Cefn du, forming a pass about half-a-mile wide, while the shores of the lakes are all along bounded by steep and lofty slopes which would throw the whole weight of the accumulated ice into the nearly level trough between them. That the grinding power here was very great is evidenced by the fact of the shores of these lakes presenting finer cases of striation and grooving, of mamellation, and of complete planing off of the softer rocks, than are perhaps to be found any where else in Wales. Now most of the other lakes show exactly the same arrangement,—wide upland valleys with many tributaries above them, and below them a sudden narrowing of the valley by projecting spurs. This can in most cases be sufficiently seen on the Ordnance maps, but it is still more striking to look down at the lakes themselves from a moderate elevation. Look at the two ridges that meet together at an angle and shut in the valley at the lower end of Llyn Ogwen, or the precipitous slopes that confine Llyn Cwellyn, west of Snowdon, and Talyllyn, south of Cader Idris. In these and most other cases the valleys containing lakes are of very moderate inclination or nearly flat, so that the motion of the glacier would be slow and would chiefly arise from pressure. When therefore a sudden narrowing of the channel occurred, the ice would necessarily accumulate just above the obstruction, and thus give that increased weight and grinding power which are exactly the conditions said to have produced lake basins. Without going any further into particulars, I may state generally that the situation and surroundings of many of the lakes of North Wales are just such as ought to exist if Professor Ramsay's theory be the true one.

As a glacier can only be now grinding out a lake basin in the very thickest part of its course, it is very difficult to see the operation going on. At the same time so much is known about glaciers, and so many of the facts bearing upon this question are admitted by all, that some conclusions seem quite clear. For example, all admit that glaciers do (or once did) grind down the rocks over which they pass, to some extent. The grinding is caused chiefly by the weight of the glacier, and therefore where the glacier is thickest the grinding will be the greatest. Glaciers behave like a very thick semi-fluid mass, flowing and filling up channels of varying widths, and therefore accumulating where there are obstructions to their free passage. Now where such an accumulation takes place in a valley of tolerably uniform slope, there will be more weight

and more grinding power than elsewhere, and thus hollows must be formed. And a hollow once formed the ice is there so much thicker and the pressure so much greater, and thus the hollow *may* increase more rapidly the deeper it goes. Then there comes the objection, that when the hollow is deep the ice at its bottom will be motionless, the upper layers sliding over the lower ones.

But who really knows this? It is a pure supposition; and there seem to be as good arguments on one side as on the other. And who, of all our philosophers previous to direct observation, would have supposed that glaciers could flow at all, and retain their form and continuity? The fact seems to be, that these huge ancient glaciers, spreading over hundreds of miles of flat country half-a-mile thick, are too vast for us to say what they could have or could not have done.

It is proverbially hard to prove a negative, and at present there is really no positive theory before the world, except Professor Ramsay's, that in any way explains either the overwhelming proportion of lakes situated in glaciated regions—or the fact that so many of the great lakes of Switzerland and Italy are situated exactly where they should be if they were ground out by glaciers,—or that the size and depth of the lakes correspond to the admitted size and thickness of the ancient glaciers. Many who oppose this theory will perhaps say that they admit it to be good as regards the smaller lakes and tarns, but uphold the elevation and subsidence theory for the larger ones. But this will in no way avoid the difficulties of distribution I have already pointed out, since the large lakes are very numerous and, as well as the small ones, abruptly cease before reaching the limits of the ancient glaciers,—limits, it must be remembered, traced before this theory was enunciated, and by men who even now do not all adopt it. Again the lakes form such a continuous series in position, form, and magnitude, that the presumption is against their having been formed by two quite distinct processes. Lakes have, no doubt, been sometimes formed by disturbance, tilting, or subsidence; but these are evidently exceptional causes, and are not to be assumed in any particular case unless they can be proved.

In connection with this subject, I may allude to one main point of difference which has existed among geologists almost since the subject first attracted attention, and which still exists. It is the question whether the glacial phenomena, so abundant over the whole of the northern half of North America, have been produced by enormous aërial glacial masses, covering at once or at different times the whole country,—or by icebergs floating down over it and grating along a shallow sea-bottom. Agassiz first propounded the "glacier" theory, and still upholds it. Sir W. Logan supports the same theory, and Professor Ramsay of course considers

that the vast American lakes are to some extent a proof of it. On the other hand Sir Roderick Murchison, Sir Charles Lyell, and Mr. Dawson, all geologists of the greatest eminence, maintain the "iceberg" theory. Exactly the same difference of opinion occurs as to many other countries, such as North Russia, Finland, and even Scotland, but we will now consider America only, because I wish to state one difficulty which I cannot find alluded to in all that has been written on the subject in this country. The iceberg theory supposes that all the lake regions of North America were about a thousand feet under the sea at a very recent period, that the country was then ground and striated by icebergs, and has since risen to its present level. Now the great lakes, Michigan and Huron, are a thousand feet deep, their bottoms being about four hundred feet below the sea-level. When the land rose up these vast basins must have been full of salt water. What has become of it? No doubt it would soon run off at the surface, and be replaced by fresh, but as a mere physical problem, would *all* the salt water from a thousand feet deep be carried off by the influx and efflux of fresh water? Has water ever been brought up from the bottom of these lakes, and is it as fresh as that of the surface? *

But even if no trace is or ought to be found of the salt-water lakes that must so recently have existed, a difficulty of a totally different nature arises. These lakes and all the lakes and rivers north of them to the Arctic ocean now contain great abundance and variety of fresh-water fishes, and among them are many found in the lakes only and some entirely confined to single lakes. There are about twenty-two of these American lake-fishes described by ichthyologists, most of them quite distinct and well-marked species, found nowhere else in the world. About twelve are confined to the group of the Great lakes, and there is one distinct genus of the perch family (established by Cuvier) which has never been found except in Lake Huron. Now the glacial epoch is post-pliocene; that is, it is within the period of existing species. The mollusca were all identical with those now living; the vertebrates have been changed a little, but chiefly by the extinction of some species. How then are we to explain the occurrence of so many peculiar species and one *peculiar genus* in fresh-water, lakes the whole district around which was so recently under the sea? It may be said that the same difficulty affects the glacier theory, for if that be true, the lakes were only made by the ice and were not in existence till it left them. To this it may be answered that the country round the lakes in every direction was in existence though the lakes were not, and we need not suppose the whole land to have been covered with ice at once. It probably took different directions

* I am informed by an eminent physicist, that by the process of diffusion the whole of the salt water would no doubt in time be carried off.

at different times, according to slight changes of climate and slow movements of the surface, and it is in accordance with all we know of the laws that have determined the distribution of animals, that so striking a modification of the physical geography of a country as the formation of thousands of lakes should lead to many changes and restrictions of the ranges of all animals, and especially of the fishes. The lakes may have proved more congenial to some which had hitherto been confined to one or two streams only, and may have preserved others from extinction which were just dying out. But on the iceberg theory the difficulty is immensely greater; for all the country north of the lakes (and much also south of them) as well as westward, almost to the bases of the rocky mountains, is so level that it must have been all under the ocean together; and it becomes difficult to understand where the great variety of fishes now inhabiting the streams and lakes of these regions can have come from, or how in so comparatively short a time they can have become modified into distinct local species. I leave this interesting ice-problem to those among my readers who take an interest in the great case of "Glacier *v.* Iceberg," now being argued in the High Court of Physical Science.

V. THE FUTURE WATER-SUPPLY OF LONDON.

By Edward Hull, B.A., F.G.S., of the Geological Survey of Great Britain.

The next Session of Parliament will probably be occupied with the consideration of two rival schemes for the supply of the Metropolis with water from distant sources, planned by engineers of eminence on gigantic proportions. That some distant source of supply is needed to replace the present arrangement, has been for some years foreseen by those who have taken an interest in the matter. Not only is the water from the Thames, the Lea, and other sources from which the Water Companies draw their supplies, destined shortly to become insufficient for the requirements of the inhabitants, but it is far from pure, containing in sensible quantities not only the salts of lime and magnesia which render it "hard," but organic matter derived from the villages and towns situated along the banks of these streams. Now of all the disadvantages which can effect a large city none is more intolerable than the want of pure water. It is a prime necessity of health and comfort, which every day's experience renders more obvious; nor can we doubt that the

deadly effects of cholera in the East of London received an impulse, amongst other causes, from the impurity of the water supplied to the inhabitants of those districts.

Of all cities in the world the Metropolis of the British Empire ought to be the first in procuring for itself all the elements of healthful existence. It has a population of 3,000,000 souls, ever increasing. It is the residence during some part of the year of the Court, the Parliament, and the aristocracy of rank and intellect: it is the common property, not of a county or a district, but of the nation, and hence whatever affects its social condition interests the nation at large.

We should like to know from those enthusiastic philanthropists, the total abstainers, for whose opinions we entertain respect, whether such of them as may be residents in Glasgow, Manchester, Liverpool, or Birmingham, ever make the hazardous experiment of quaffing a glass of cold water fresh from the cistern or pipe in the city of London. If so, we venture to think their principles must sustain a severe test on such an occasion. For ourselves we are perfectly sincere in saying, that unless the water were previously boiled, it would require a large sum to induce us to perform a feat to which we are by no means unaccustomed in many of the large towns of the North. Boiling and filtration will no doubt render London water to a great degree innocuous, but it certainly does not render it palatable; and it can scarcely be denied that a supply which requires in its use such precautions is not adapted for general consumption.

No blame can be attached to the Water Companies for this state of things. They have endeavoured to turn to account the sources which were conveniently at hand, and the water drawn from them undergoes a process of filtration through sand and gravel. But it ought to be thoroughly understood, that no such process can eliminate the soluble or microscopic ingredients which render water derived from an inhabited district unfit for human uses. That too-celebrated London pump, which was the cause of death to 600 persons, is said to have yielded water which was apparently clear and good.

The water-supply of a large town ought to be derived either by pumping from considerable depths in the solid strata in a thinly inhabited district, or by utilizing the streams which descend from mountainous tracts where the population is scant and the rainfall abundant. The position of London renders it admirably adapted for receiving its water-supply from wells. The London basin is indeed a great natural reservoir, from which large quantities of water are already obtained by wells sunken through the Tertiary Clay into the Chalk formation, and is capable of yielding much more. Even were the supply from the Chalk and Green Sand