ON THE RELATIVE

POWERS OF GLACIERS

AND

FLOATING ICEBERGS

IN

MODIFYING THE SURFACE OF THE EARTH.

BY

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In the last Anniversary Address* I directed your attention to the state of Greenland as it is, in order to impress upon the minds of our Fellows who have not attended to the connection between existing geography and the ancient conditions of the globe, that Scotland and large portions of Northern Europe must, at a period anterior to the creation of man, have been in the same condition as that in which Greenland and its adjacent seas are now. In other words, that, in the glacial epoch of geologists, certain elevated tracts were permanently occupied by fields of snow, with glaciers descending from them to the bays and cliffs of the sea, and that the erratic blocks which we now find spread over central England and the plains of Germany are simply the relics of icebergs which floated over wide tracts then submerged, and which, on melting, dropped them on the then sea bottom.

In the last session the vivid descriptions of the glaciers of Western Tibet, by Captain Godwin Austen, and of the glaciers of the middle island of New Zealand, by Drs. Haast † and Hector,‡ have

* See 'Proceedings,' vol. vii., No. 4, and 'Journal,' vol. xxxiii., Royal Geographical Society.

† Dr. Haast (as before-mentioned) has sent to our Society a series of coloured sketches of the Glaciers of the Western Coast of the Province of Canterbury, which for striking effect seem to me never to have been surpassed by any delineator of icy regions. The juxtaposition of these glaciers to a splendid forest vegetation, and amidst mountains which are close to the sea, and yet rise to 10,000 feet above it, the depth of the gorges, and the height of waterfalls issuing from the ice, are all very remarkable.

‡ By a letter just received from Dr. Hector, dated 20th January, 1864, I learn that not only has he ably explored the region occupied by glaciers in the province of Otago, but has also visited, in a steamer, the wonderful fiords on the western side of the island. He is now preparing a work on the geological structure of the colony, in which he will show that the lakes on the eastern slopes of the country are true rock basins, which were once occupied by glaciers, and the bottom of one of which sounded by him has a depth of 1250 feet, or considerably below the sea. Although Dr. Hector does not go so far as to express his belief that these rock-basins have been scooped out by ice, he suggests that they have been filled and shaped by glaciers. He avows, however, that he has to read up much on this subject, and I only regret that this portion of my Address cannot probably be in the hands of my distinguished friend before his final conclusions may be published.

specially attracted the attention of the Society; and I am therefore led to dwell on these grand terrestrial phenomena by giving a general view of the results of glacial action, both terrestrial and subaqueous.

When the first of those Memoirs was read, Dr. Hugh Falconer, who had passed several years in that same region of the Tibetan Himalayas, enlarged upon the scenes which had been so graphically delineated on maps by Captain Godwin Austen. He then referred us to the works of those who preceded and followed him in examining that region, and reminded us of the names of Moorcroft, Trebeck, Jacquemont, Vigne, Strachey,* and Thomson.

In considering the subject of glaciers, I am bound specially to call your attention to the last-mentioned of these explorers, Dr. Thomson, who first well defined the characters and extent of the glaciers of Western Tibet. In addition to a masterly description † of the physical geography of the regions he traversed, the work of Dr. Thomson is also so rich in botanical, climatological, and geological researches as to be a model for geographical explorers. Thus, his original observations on the enormous lacustrine deposits, replete with the remains of fresh-water shells, accumulated formerly at vast heights above the sea, are to my mind the grandest and clearest proofs of how the feeders of the Indus in bygone periods were dammed up by rock barriers, which later acts of upheavement may have disrupted, or by gigantic transverse or terminal glaciers and their moraines. In truth, therefore, the parallel roads of Lochaber in our Highlands, to which I adverted last year, have their grander analogue in the vast horizontal terraces of the mountains of Tibet. Again, among the remarkable data set before us in that work, is the striking fact that in the trans-Sutlej region of the Himalayas, the glaciers which descend from the southern flank of a range of mountains are longer than those which occur on the northern flank of the same. This is accounted for by the author on the grounds of the great amount of moisture proceeding from the ocean being arrested and condensed into snow by the first great range of heights which it encounters. The same phenomenon was, indeed, met with in Sikhim by Dr. Joseph Hooker, in the eastern portion of this great chain. Unlike his precursors, Thomson, when he wrote, was already conversant with

* In 1847 Lieut. R. Strachey visited and described the glaciers of the Pindur and Kuphinee Rivers, and applied to them the excellent Alpine classification of Professor James Forbes.

† 'Travels in the Western Himalayas and Tibet.' 1852.

the true laws of glacier movements, as well as the most remarkable of their effects, as pointed out in various works by Agassiz and other writers upon the Alps, and he specially refers to Professor James Forbes; for, though many an ardent traveller had preceded him, Thomson was the first who clearly distinguished the glaciers of the Himalayan Mountains from the snows whence they issued, and who at the same time pointed out the lateral and terminal moraines which they evolved. That which Thomson did for the western or Tibetan portion of this lofty chain of mountains was, in like manner, admirably done by Dr. Joseph Hooker for the eastern mountains of Sikhim, in his most attractive work.*

All these observers, whether in India or in New Zealand, have taught us that the glacial phenomena, though on a much grander scale in the Himalayas, are precisely analogous to those in Europe. The application, however, of accurate topographical surveying, and the ascertainment of the precise length and breadth of those grand rivers of ice, were wanting. Captain Godwin Austen has effected this, as regards those vast glaciers proceeding from the Mooztagh, which lie to the west of those descending from the Karakorum Pass, described by Thomson. Having measured the length and breadth of these masses, he has enabled us to know that one of them, which feeds the powerful affluent of the Indus called Shiggar, has a length of 36 miles, and is therefore upwards of three times the length of any existing glacier of the Alps; though it will presently be shown that some of the old Alpine glaciers were considerably longer. Well, indeed, may we account for these enormous dimensions now existing in the Himalayas, when we recollect that the passes by which travellers proceed to Yarkand have a height of 18,000 feet, and that the great Karakorum Peak rises to 28,200 feet, above the sea. Captain Godwin Austen is, I understand, about to explore the great *terra incognita* which the Burhampooter is supposed to traverse in the upper part of its course, and we may confidently hope that, at no distant day, this energetic young officer will ultimately obtain the highest honours of this Society.

In the discussion which followed the reading of the memoir of Captain Godwin Austen, Dr. Falconer grappled most ably with the novel theory that the lakes of the Alps owe their origin to the erosive action of ice, which, descending from former great glaciers, has excavated or scooped out the cavities now filled with water.

* See 'Himalayan Journals.' 1854.

Being one of the few men who have personally examined the glaciers both of the Himalayas and the Alps, his reasoning from observed facts is most valuable. Believing, with the vast majority of practical geologists, that the irregularities of the surface of the Alps have been primarily caused by dislocations and denudations, he gave it as his opinion that the Alpine cavities, having been filled with ice during the glacial period, were thereby protected from the influx of the vast masses of the detritus hurled down in the moraines of gigantic glaciers that passed over these countries on solid ice, which, on melting, left the depressions in the condition of lakes. On the southern flank of the Himalayan mountains, on the contrary, where ice has not acted as a conservative agent, the valleys have been choked up with débris, but no great lakes exist. Dr. Falconer expressed the same views at an evening meeting of the Geological Society, on the 5th March, 1862, but it is not the practice of that body to record the opinions of speakers.

In alluding to this original view of Dr. Falconer, and to his able illustration of the whole subject, as detailed in our Proceedings,* I am bound, as a geologist, not to shrink from stating that I agree with him. I beg also to take this opportunity of recording my own opinion of the effects which glaciers have produced in those tracts where they formerly existed, or where they now prevail, as founded on the observations of many good observers, as well as on my own researches. Until lately geologists seemed to be generally agreed that most of the numerous deep openings and depressions which exist in all lofty mountains were primarily due to cracks, rents, and denudations, which took place during the various movements which each chain had undergone at various periods. These apertures, it was supposed, were necessarily enlarged by long diurnal atmospheric agency and the action of torrents carrying down boulders and detritus; such action being most intense in those mountains where snows and glaciers prevailed, the melting of which necessarily produced great débâcles. In the place of this *modus operandi*, another theory has been applied to all those mountains, which, like the Alps, have been for long periods the seat of glaciers.

Before I enter on the consideration of the new theory of the power of moving ice, let us take a review of the progress recently made in pointing out the extent to which ancient glaciers and their moraines have ranged within or on the flanks of the Alps.

* 'Proceedings of Royal Geographical Society,' vol. viii. p. 38.

In the northern portions of the chain these phenomena long ago attracted the attention of some admirable observers. Originating with Venetz and Charpentier, the true active powers of glaciers were defined by Rendu, Agassiz, and Forbes, and subsequently by the other explorers. In short, no doubt any longer obtains, that such was the powerful agency of the grand ancient glaciers, that blocks of crystalline rock were transported by them from the central Alps of Mont Blanc to the slopes of the Jura Mountains. When, however, we begin to seek for satisfactory explanations of the method of transport of these huge erratics, geologists (who are only geographers of another order) entertained different opinions. For my own part, I have had strong doubts as to whether the great blocks derived from Mont Blanc, and which lie on the slopes of the Jura, were ever borne thither by a vast solid glacier which advanced from the Lake of Geneva over the Cantons of Vaud and Neufchatel. Whilst fully believing in the great power of glaciers and their agency, my opinion was that these blocks were rather transported to their present habitats on the Jura on ice-rafts, which were floated away in water to the N.N.W., when the great glaciers melted, and the low countries were flooded. I founded this opinion on the fact, that in examining the Canton de Vaud, and particularly the tracts near Lausanne and the north side of the Lake of Geneva, I never could detect the trace of true moraines. In that detritus I saw merely accumulations of loose materials, which had all the aspect of having been accumulated under running waters. But, even granting to the land-glacialists their full demand, and supposing that a gigantic glacier was formerly spread out in fan shape, as laid down by several geologists and recently in the little map of Sir Charles Lyell, in his work on the Antiquity of Man, and that it became eventually of such enormous thickness as to have carried up the great blocks on its surface, to lodge them on the Jura Mountains; there is still in it nothing which supports the opinion, as indeed Sir Charles has himself observed,* that the deep cavity in which the lake lies was *excavated* by ice.

The geologists who first embraced the view of the transport of the huge blocks on the Jura by a solid glacier, were of opinion, that the great depressions and irregularities of the surface which we now see between the Alps and the Jura, including the Lakes of Geneva and Neufchatel, were so filled up with snow and ice, that

* See 'Antiquity of Man,' p. 312.

the advancing glaciers travelled on them as bridges of ice, the foundations of which occupied the cavities.

Let us now turn to the south side of the Alps, where a long incline accounts for the enormous extension of glaciers into the plains of Italy. Thus, in examining the remains of the old glaciers which once advanced into the valley of the Po, MM. Martins and Gastaldi show us, that one of those bodies extended from Mount Tabor to Rivoli, a length of 50 miles; and, therefore, was longer than any existing glacier described on the flanks of the Himalayas;* whilst those to the south of the Lago di Garda are shown to have had a much greater length. Demonstrating, along with many other authors, how these old glaciers had striated and polished the hard rocks through or on which they had advanced, these authors also clearly pointed out how the course of the glaciers had been deflected, so as to take a new direction, when they met with the obstruction of any promontory of hard rock. Further, M. Martins, being well acquainted with Norway, indicated that, just as in that country, the face of each rock in a valley was rounded off, polished, and striated where it had been opposed to the advancing mass of ice, and that its opposite or downward face, over which the ice had cascaded or tumbled, was left in a rough state; thus exhibiting the worn or "stoss-seite," and lee, or protected side, of the Scandinavian geologists. The subsequent works of M. Gastaldi on the geology of Piedmont, in 1853 and in 1861, bring within well-defined limits the phenomena of old moraines and ancient drift, and prove that the débris carried over each gorge and valley has been derived from the rocks which specially encase such depressions. He also clearly demonstrated that in many of these cases the gigantic boulders, which are piled together and present the character of a cataclysmal origin, can all be accounted for simply by the power of advancing ancient glaciers. In these works M. Gastaldi very properly distinguishes between the erratic blocks which were evidently parts of old terrestrial moraines, and those which, associated with tertiary strata, are found in deposits with marine shells —the larger erratics in the latter, as in the Superga, having been transported in masses of ice which floated on the then sea.

Various other Italian authors have occupied themselves with glacial phenomena (particularly Omboni, Villa, Stoppani, Cornalia, Paglia, Parolini, &c.): the conclusion at which they have all arrived

* Bull. Soc. Géol. de France. 1850.

is, that there existed an enormous extension of the moraines sent forth by the ancient Alpine glaciers into the great valley of the Po. Geographers who have not studied the phenomena may well indeed be surprised when they learn, that the hills to the south of the Lago di Garda, and extending by Pozzolengo and Solferino to Cavriano,* or the very ground where the great battles of the year 1859 were fought (the hill of Solferino being 657 English feet above the sea), are simply great moraines of blocks and gravel, produced by the advance of former glaciers which issued from the southern slopes of the Alps.

Combining these observations with others of his own on the lake of Annecy, M. Mortillet suggested in 1862 a new theory, in attributing to the descent of the glaciers a great excavating power. Believing, with all those who have been named, as well as the most eminent of the Swiss and French geologists, that the last great upheavals and denudations of the Alps had produced the irregularities of their surface, he inferred that before the glacial period began, the débris derived from the wear and tear of the mountains by watery action had, to a great extent, choked up the valleys and filled the rock-basins. He further believed that, in the cold period which followed, great glaciers, descending with enormous power, forced all such débris out of the original rock-basins, and left them to be occupied by the present lakes. It is proper here to state that M. Gastaldi was right, as well as M. Mortillet, who followed him, in presuming that great deposits of old water-worn alluvium or loose drift were accumulated before the formation of glaciers, inasmuch as the oldest moraines are seen to repose in many places on the former. It will presently be shown that this fact contains within it the proof that the glaciers were not and are not in themselves excavating bodies.

Preceding M. Mortillet, however, in reasoning upon the excavating power of former glaciers, my eminent associate Professor Ramsay had broached a much bolder theory. In his essay entitled 'The Old Glaciers of Switzerland and North Wales,' published in 1859, and re-published with additions in 1860, he expressed the opinion that the excavation of deep hollows in solid rocks was due to a weight of superincumbent ice pressing and grinding *downwards and outwards*, over high, flat, and sometimes broad watersheds and table-lands, during that period of intense

* See Paglia—'Sulle Colline del Terreno Erratico all' estremità meridionale del Lago di Garda' (with map).

cold which produced the old glaciers.* In 1862 he went still further; and whilst M. Mortillet was communicating his views on the Continent, Ramsay, wholly unconscious of what M. Mortillet was doing, read a memoir to the Geological Society of London, showing that all the cavities occupied by lakes in Switzerland and the North of Italy had been excavated originally by the action of glacier ice. Whatever, therefore, be the fate of this ingenious view, Professor Ramsay has our thanks for having excited much useful inquiry, and for having compelled old geologists like myself to reconsider our conclusions.

If the view of M. Mortillet has been met with objections, still more is the theory of Ramsay opposed, and particularly in foreign lands. In this country it has indeed met with the most vigorous opposition on the part of Dr. Falconer, as recorded in our Proceedings; and even Sir Charles Lyell, the great advocate of the power of existing causes, has stoutly opposed this bold extension of a most powerful *vera causa*.† Having explored the Alps, at various intervals, for upwards of forty years, I long ago came to the conclusion that their chief cavities, vertical precipices, and subtending, deep, narrow gorges, have been *originally* determined by movements and openings of the crust, whether arranged in anticlinal or synclinal lines, or not less frequently modified by great transversal or lateral breaks, at right angles to the longitudinal or main folds of elevation and depression. Explorations of other mountainous regions, in various parts of Europe, have strengthened this conviction. I rejoice, therefore, to find that those geologists of Switzerland, who justly stand at the head of their profession, Professor Studer and M. Escher von der Linth, have sustained, by numerous appeals to nature, the views I hold in common with the great majority of geologists. Those Swiss explorers, who have laboured for many years in their native Alps, and have constructed admirable geological maps of them, must surely be well acquainted with the ruptures of the various rocks, the outlines of which they have sedulously followed. Now, they attribute most of those deep cavities in which the rivers and lakes occur either to dislocations producing abrupt fissures, or to great foldings of the strata leaving openings upwards where the tension has been the greatest—openings which were enlarged by powerful

* See 'Peaks, Passes,' &c. (Alpine Journal, 1859), and 'The Old Glaciers of Switzerland and North Wales,' London, 1860, p. 110.

† See 'Antiquity of Man,' pp. 316 *et seq.*

denudations. Numerous geologists have recently expressed their concurrence in the generally-adopted view, that the Alpine lakes occupy such orographic depressions; and, by close researches, my accomplished friend Mr. John Ball * has ably sustained this view, and has further shown how slight is the erosive power of a glacier even when issuing from its main source. No one of them, in short, any more than Professor Studer and myself, doubts that the origin of these lakes is primarily due to other causes. Nor am I aware that any geologists of France and Germany, much as many of them have examined the Alps, have deviated from the opinion that the main diversity of outline in that chain was due to ruptures and denudations that occurred during the upheavals of the chain.

On the other hand, I am bound to state that, although the new theory has met with little or no favour on the continent of Europe, it is supported by our able geologists, Jukes and Geikie. Again, whilst Ramsay extended his view to the great lakes of the Alps, the eminent physicist Tyndall speculated even upon all the Alpine valleys having been formed by the long processes of the melting of snows and the erosion of ice.† With every respect for the reasoning of my distinguished countrymen, I rely upon my long acquaintance with the structure of the Alpine chain; and now that I see sound practical geologists, who have passed their lives in examining every recess of those mountains, rejecting this new theory, and pointing out, in place of it, the proofs of ruptures and denudations in the chain, I adhere firmly to the view I have long entertained.‡

Those who wish to analyse this matter, must consult the admirable essay of Professor Studer on the origin of the Swiss lakes.§ They will find numerous proofs of the views sustained

* See 'Phil. Mag.' 1863.

† See Tyndall on the Conformation of the Alps, 'Phil. Mag.' vol. xiv., 1862, p. 169, and also Ramsay on the Excavations of the Alps, xvi. p. 377.

‡ Some remarkable facts have been mentioned to me in a letter by M. Escher von der Linth, as proving the inapplicability of the ice erosion theory to the Swiss lakes. 1st. That the glacier of Rosenlaui, which descends from a great altitude, does not enter a low deep narrow gorge of the valley, but forms a bridge over it; and so it is to be inferred, that, as the ancient glacier did not excavate this gorge, still less did it excavate the great valley in which the present glacier is embosomed. Again, he points out that, as the bottoms of many of the Swiss lakes are below the level of the sea, the glacier which is supposed to have excavated the hollow would have to ascend considerable heights to emerge from the depression which it had excavated—an impossible movement, and contradicted by the existing operations of all glaciers.

§ 'Origine des Lacs Suisses,' Biblio. Univ. et Revue Suisse (Arch. des Sci. Phys. et Nat.) t. xix. liv. de Février, 1864; also Phil. Mag. vol. xxvii. p. 481.

by the leader of Alpine geologists. He shows you, indeed, how many of the rivers now flow in fissures or deep chasms in very hard rocks of different composition; chasms which water alone could never have opened out, particularly in those cases where the river has left a softer rock, and, with very slight obstacles to its straight course, has availed itself of one of these deep transverse natural gorges, which have evidently been produced by a great former rent. My personal observations in the Alps, Carpathians, and Ural mountains enable me to confirm this view. As regards the continent of Europe, I should transport you to the Rhine, the Danube, and other great streams, which, flowing through flat countries, with little declivity, never could have eroded those deep, abrupt gorges through which they here and there flow, and which are manifestly due to original ruptures of the rocks.*

In holding these opinions as to the small power of watery or glacial action, when not acting on an adequate incline, I do not doubt that glaciers have been, and still are, most important agents in modifying the outlines of mountains. Their summits are, we know, continually degraded by rains and melted snows; and torrents flowing down from them and carrying much detritus, are, doubtless, deepening their channels wherever sufficient slopes occur. But to whatever extent this agency has been and is at work, and to however great a degree a descending glacier may scratch and round off the rocky bottom on which it advances, I coincide with Professor Studer, and many other observers, that the amount of erosion produced by these icy masses, particularly when they have advanced into valleys where there is only a slight inclination, must be exceedingly small. In valleys with a very slight descent it will presently be shown that, even in the Alps, no erosion whatever takes place, particularly as the bottom of the glacier is usually separated from the subjacent rock or vegetable soil by water arising from the melting of the ice. Again, in all the steeper valleys down which ancient glaciers have formerly descended, we do not find that either the sides or bottoms of the upper gorges afford any proof of wide erosion, but only exhibit the peculiar fashioning of the flanking surfaces of the rocks, or that rounding off and polishing, called

* The recent Russian exploration of Eastern Siberia has shown how the grand river Amur deflects suddenly at nearly right angles from its course in a comparatively low country, to take advantage of a deep natural rent in the mountains through which it escapes to the seaboard (see p. 201 of the present Address to the Royal Geographical Society).

moutonné, accompanied with striations. On the contrary, in gorges whence the largest glaciers have advanced for ages, we meet with islands of solid rock and little bosses still standing out, even in the midst of valleys down which the icy stream has swept.

With such proofs before us of what the frozen rivers called glaciers have done and are doing in the high valleys, how can we imagine, as Dr. Falconer has forcibly put it, that the glacier which is supposed to have occupied the Lago Maggiore, for example, and had advanced its moraines into the plains of the Po, should have had the power to plough its way down to a depth of 2000 feet below the Mediterranean, and then to rise up along an incline at the rate of 180 feet per mile? Nor can I admit the possible application of this ice-excavating theory wherever I see that a depression in which a lake occurs is at right angles to the discharge of an old main glacier. This is remarkably to be noticed in the case of the Lake of Geneva, which trends from E. to W., whilst the detritus and blocks sent forth by the old glacier of the Rhone have all proceeded to the N. and N.N.W.; or in direct continuation of the line of march of the glacier which issued from the narrow gorge of the Rhone. By what momentum, then, was the glacier to be so deflected to the west that it could channel or scoop out, on flat ground, the great hollow now occupied by the Lake of Geneva? And, after effecting this wonderful operation, how was it to be propelled upwards from this cavity on the ascent, to great heights on the slopes of the Jura mountains?

Still stronger objections exist to the application of the excavation theory to the Lake of Constance. There I have never been able to see on the northern flank of the Hohe Sentis, which presents its abrupt, precipitous, and highly dislocated and contorted jurassic and cretaceous rocks to the lake, with terraces of miocene deposits, at various heights,—there I have been unable, when with my indefatigable friend and companion M. Escher von der Linth, who knows every inch of the ground, to trace the signs of the action of a great glacier, which could, in its descent, have so plunged into the flat region on the east and north, as to have scooped out the cavity in which the Lake of Constance lies. In this case, indeed, there are no traces whatever of those great old moraines from the relics of which we infer that glaciers have formerly advanced; the level country to the north of the lake being entirely free from them.

Great orographic depressions and deep cavities, sometimes dry,

sometimes filled with water, occur in numberless countries where no glaciers ever existed. Thus, in Spain, as my colleague M. de Verneuil assures me, the large depressions on either side of the granite mountains of the Guadarramma present exactly the appearance which a theorist might attribute to excavation by ice, and yet, however these cavities were formed, it is certain that no glacier has ever existed there. Nor, again, has ice ever acted on the sides of the steep mountains of Murcia, where deep excavations and denudations are seen upon the grandest Alpine scale.

If we transport ourselves from those southern climes to the northern latitudes of the Ural mountains, where doubtless ice and snow formerly prevailed to a greater extent than now, we do not there find any proof whatever of the action of glaciers; for the hills are much too low to have given propulsion to such masses. On the contrary, we know that great blocks of hard rocks have been transported to the foot of these hills from Lapland and Scandinavia, when, during the glacial period, a vast Arctic Sea watered the flanks of the Ural mountains, and when most parts of that low chain could then have been only slightly elevated above the waters. And yet on the sides of this chain, where no glaciers have ever so acted as to have produced erosion, we meet with both longitudinal and transverse deep fissures in some of which lakes, and in others rivers, occur. Thus, all along the eastern flank of the Ural mountains we find a succession of depressions filled with water without a trace, on the sides of the bare and hard rocks which subtend these lakes, of any former action of glaciers. Then, as to deep valleys in which rivers flow, let us take two out of the examples along the western flank of this chain, on which my companions De Verneuil, Keyserling, and myself have specially dwelt in our work on Russia. The Serebrianka river, as it issues from a network of metamorphic schists, quartz rocks, and marbles of Silurian age, exhibits on its rugged banks the extrusion of much igneous matter. This agency has split up the stratified deposits; and the necessarily accompanying movements have caused great openings, including the cavity in which the river flows. Or, when the geological traveller passes from the valley of the Serebrianka to that of its recipient, the Tchussovaya, still more is he struck with wonderment at the unquestionable evidences, amidst intensely dislocated rocks, of the ruptures by which the deep narrow chasm has been formed in hard crystalline rocks, in which a lazy stream flows, which, not descending from any

altitude, has had no excavating power whatever, and, like our own meandering Wye, has flowed on through clefts in limestone during the whole historic and prehistoric period, without deepening its bed.*

But if rivers which are not torrential, and do not descend from heights, cannot possibly have produced, nor even have deepened, the natural hollows or chasms in which they flow, still it might be contended, that, what water has not effected, may have been done by a river, when, in the compacter form of ice, it descended and advanced across the lower country. Unluckily for the supporters of the ice-excavating theory, the data which existing nature presents to us, as before said, are decisively opposed to their view. The examination of those tracts over which glaciers have advanced, and from which they have retreated, shows, in the most convincing manner, that ice has so much plasticity that it has always moulded itself upon the inequalities of hard rocks over which it passed, and, merely pushing on the loose detritus which it meets with, or carries along with it from the sides of the upper mountains, has never excavated the lateral valleys, nor even cleared out their old alluvia. This fact was well noticed by the Swiss naturalists, as evidenced by present operations, at their last meeting in the Upper Engadine, and has been well recorded by that experienced and sagacious observer of glacial phenomena, M. Martins.

Since that time the able French geologist, M. Collomb, who was associated with Agassiz in his earliest researches on glaciers, and has been the companion, in Spain, of my colleague M. de Verneuil, has recently put into my hands the results of his own observation upon the present and former agency of the glaciers of the Alps, which decisively show that ice, *per se*, neither has nor has had any excavating power.‡ None of the glaciers of the Alps cited by M. Collomb, viz. those of the Rhone, the Aar, the Valley of Chamounix, the Allée Blanche, and the Valley of Zermatt, produce any excavation in the lower grounds over which they pass. That of Görner, which, among others, is advancing, affects

* For a full description of the abrupt gorge of the Tchussovaya, see 'Russia and the Ural Mountains,' vol. i. p. 352 *et seq.*

† See 'Revue des Deux Mondes,' Mars, 1864. The former observations of M. Martins on Norway and on the Alps are of the highest importance.

‡ I may add that M. Collomb expresses that which I believe to be the opinion of Elie de Beaumont, d'Archiac, de Verneuil, Daubrée, and all the leading French geologists.

very slightly the surface of the meadows on which it proceeds, and does not penetrate into the soil. Again, where the glacier of the lower Aar pushes, on its front, upon accumulations of the débris of old moraines and gravel, it scarcely deranges these materials, but slides over them, leaving them covered with mud and sand, but not excavating them. Also, the glacier of the Rhone, the principal part of which can be so conveniently studied, advances on a gravelly substratum, in which it does not form a channel. Such being the facts as regards glaciers now advancing, M. Collomb cites equally strong, if not still stronger, cases, in support of his view, as derived from the observation of retiring or shrinking glaciers in the valleys of the Alps. Examining last year with M. Daubrée the glaciers of the Valley of Chamounix, he was attracted to that named Bossons, which he had not seen for five years. During that time the glacier had shrunk very considerably, both in altitude and length, and yet upon the surface of the ground from which it had retired there was not the smallest sign of excavation.

Viewing a glacier as a plastic body, we know that it is pressed onwards by gravitation from the increasing and descending masses of snow and ice behind it in the loftier mountains, and being forced to descend through narrow gorges, it naturally acts with the greater energy on the precipitous rocky flanks of these openings; striating and polishing them with the sand, blocks, and pebbles which it holds in its grasp. But, as before touched upon, the narrowness of many of those channels through which glaciers have been thrust for countless ages, is in itself a demonstration that the ice can have done very little in widening the gorge through which it has been forced, and where, of necessity, it exerted by far its greatest power. In other words, the flanking rocks of each gorge have proved infinitely more stubborn than the ice and its embedded stones, which have merely served as gravers and polishers of the granites, quartz rocks, porphyries, slates, marbles, or other hard rocks, among which the frozen river has descended. And, if such has been the amount of influence of advancing glaciers in the higher regions, where the body descends with the greatest power, how are we to believe that when this creeping mass of ice arrived in low countries (as for instance in the depressions occupied by the Lakes of Geneva and Constance) it could have exerted a power infinitely greater than that which it possessed in the higher regions?

When we turn from modern glaciers to the remains of those of ancient date, the proofs are equally decisive, that, whatever

might be their extent, those gigantic bodies exercised no excavating power. I am reminded by M. Collomb, as well as by M. Escher von der Linth, that in many parts of the Alps, vast old moraines repose directly on incoherent and loose materials of quaternary age; the old drift of the Alps, containing *Elephas primigenius* and *Rhinoceros tichorhinus*. Well may we then ask, how is it that the ancient and larger glaciers, which were supposed to have had such enormous excavating power as to have scooped out deep valleys in hard rocks, should not have entirely destroyed the loose accumulation of gravel over which they have been spread? Or, if glaciers excavated the Lago di Garda and Lago Maggiore, why did they not produce any such effect at Ivrea, in the Valley of Aosta, down which we know that enormous masses of ice travelled; or at Rivoli, in their march from Mount Cenis towards Turin?

Leaving it to physical philosophers, such as Forbes, Faraday, Hopkins, and Tyndall, to show what is the real measure of the abrading power of masses of moving ice, I simply form my opinion from what glaciers are accomplishing, or have accomplished. Judging from positive data, I infer that if, as agents, they have been wholly incapable of removing even the old and loose alluvial drift which encumbered the valleys, infinitely less had they the power of excavating hard rocks. At the same time I know that, in every mountain tract which I have examined, there have been quite a sufficient number of rents and denudations to account for all inequalities. These openings have doubtless been greatly increased by the atmospheric agencies of ages, and particularly in all those situations where water has acted with great power, during the melting of glaciers.

I have made these observations (which I could largely extend) to show the intimate connection which exists between the science of geology, to which I have been so long devoted, and physical geography. Let me explain, however, that I do not doubt that glaciers have, in certain regions, caused the formation of lakes, though by a very different agency from that of the excavation of rocks. The great glaciers of former times have unquestionably sent forth and discharged still larger accumulations of débris than those of our day, which, in the form of high terminal moraines, barred up water-channels, and the result in some mountainous tracts has inevitably been the production of lakes. Among examples of such in Europe, M. Collomb directs my attention to the Gérard-meer, on the western flanks of the Vosges mountains. This lake has been formed by an

ancient moraine, which, descending from the Vosges mountains, has been accumulated on old drifted loose materials, which it has not excavated, whilst it has served as a permanent dam to sustain the waters at a height of 1400 feet above the plain of the Rhine, to the east of the Vosges, and nearly 2000 English feet above the level of the sea.

In the grand and loftier cases, however, of Western Tibet, before alluded to, it is scarcely conceivable that icy barriers or moraines in the valleys could have risen to sufficient height to pond back the waters to many thousands of feet above the low country on the south. The bursting of those old vast and lofty mountain lakes was probably, as suggested by Dr. Falconer, determined by the last great upheaval of the Himalayas, which, judging from the very modern character of the organic remains in the upheaved deposits, must have taken place during one of the most recent of geological epochs.

In referring you to my observations of last year on the marvellous effects of those aqueous currents which have transported erratic blocks of stone during the former glacial period, I must attract your notice to a remarkable and faithfully executed new map of Finland by Professor Nils Nördenskiold, of Helsingfors, which illustrates an able memoir by that author on the scratched and polished surfaces of the rocks of his native country.* Carefully taking the direction of every one of the innumerable sets of parallel scratches over a region larger than Great Britain, he shows, that everywhere the direction of these groovings and scratches is from north-west to south-east, with slight local deviations only. Again, the worn sides (stoss-seiten) of each hard rock which has been scratched, worn down, and polished, are presented to the north-west, the point from which the force proceeded; and every *lee*, or protected and rough side, lies to the south-east. On the coast of Finland these groovings are even observed to extend in one place from many feet under the surface of the sea. Seeing that the force which produced these groovings and scratches came from beyond the Gulf of Bothnia and the low country of Sweden, and has operated with such uniformity over a vast region, parts of which rose to about 1000 feet above the Bothnian Gulf, he necessarily refers the phenomena to powerful marine currents. These took place when Finland, as well as all Northern Russia and Germany, lay under the sea, and when the chief groovings were made by stones and blocks, which were held fast in

* 'Beitrag zur Kentniss der Schrammen in Finland.' Von N. Nördenskiold. Helsingfors, 1863.

the bottom of floating icebergs, when they were arrested on submarine banks or points of rock. He also indicates how the erratic blocks dropped by these icebergs are found to be more and more rounded as they have receded from the source of their origin, or how, in drifting to the south-east, they have consequently been more exposed to wear and tear. The quantities of sea-sand which abound, and the accompanying small and waterworn pebbles and gravel, have, of course, assisted in the polishing of the rocks. The sand-ridges and pebble-beds which abound in Finland are, in fact, nothing different from the Ösar of the Swedish geologists; and thus the drift phenomena on either side of the Gulf of Bothnia are shown to be identical sub-aqueous deposits.

Here, then, we have a vast region of Europe in which it is manifest that no land-ice or glacier could ever have acted, inasmuch as the area from whence the force was directed was manifestly far to the north-west of the Gulf of Bothnia, and the low countries of Sweden, which, equally with Finland, are covered with erratic blocks and aqueously transported drift. Neither in the south of Sweden nor in Finland are there any moraines, all the detritus around the great erratics being water-worn; and yet the scratched and polished surfaces, the worn and abrupt sides of the hillocks, in both these countries, resemble precisely the *roches moutonnées* seen in the march of every existing glacier. Agreeing, as I do entirely, with Professor Nördenskiold (for in my published works I have maintained the same view as regards the southern parts of Sweden, and all Northern Russia, Prussia, and Germany),* I also agree with him in the conclusion that the depressions in the surface of Finland, which are now occupied by innumerable lakes, are those which existed when the country was a sea-bottom, and that the present lakes simply occupy the hollows which existed when Finland was raised from beneath the waters. In a table giving the lithological structure of each rock *in situ* which has been grooved, it is shown that the depth of the scratches bears an exact relation to the hardness and resisting nature of the rock. The map—on which every lake and the numerous scratched surfaces are marked, as well as all the altitudes—is a work which must elicit the admiration of every geographer and geologist, and does such honour to Professor Nördenskiold, that our Council has justly placed him in the list of our Honorary Members.

* See 'Russia in Europe and the Ural Mountains,' vol. i. chapters 20 and 21. Also, 'Quart. Jour. Geol. Soc.,' vol. ii. p. 349.

The lines of striation, so carefully laid down by Nördenskiold in Finland, I have myself found extending in the adjacent low regions of Russia, and notably upon the hard quartzose rocks forming the sides of the lake Onega, at a distance of 500 miles from the Bothnian Gulf. There, also, they are seen to be continuous from the shore under the water of the lake, being visible at some feet below the surface. In this flat or slightly undulating country we have all the same proofs as in Finland, that these scratches, groovings, and polishings could only have been produced by stones carried in icebergs; and there, as in Finland, the great erratics, referable to the north-western parts of Norway, have been dropped at numerous intervals, some of them from Lapland, extending to the western flank of the Ural mountains. In the work and map of "Russia and the Ural Mountains," published by myself and companions De Verneuil and Keyserling, the enormous area over which these erratics were transported during the period when the glacial sea covered Russia in Europe and Northern Germany was defined. It was then for the first time made manifest that the currents which transported these blocks had eccentric directions. Thus, whilst the blocks in Finland and Northern Russia had proceeded from N.W. to S.E. (having been derived from the old north Norwegian ice-fields), the blocks which covered the plains of Prussia, and extended over Poland up the great valleys, on to the foot of the Carpathians, being also of Scandinavian origin, must have been brought from north to south when all those lands were under the sea. On the east of England the great Scandinavian erratics came from the west coast of Norway, whilst in Lapland, M. Böhtlingk had shown that the blocks were diverted northwards into the icy sea.

These facts of the divergence of the distribution of the erratics, as due to divergent currents, are quite in harmony with what would be found at the present day, if the bottom of the sea could be so laid bare as to enable us to refer to the various north or south polar glaciers, or to those of Greenland, the devious lines of deposit of the blocks derived from each of these regions, as determined by different prevailing currents.

If we refer to what glaciers have effected upon land, and to those phenomena which could only have been produced when the rocks so affected were submarine, we must admit that two distinct modifications of the same great agency have produced similar results. The great mass of low country in North America, the surface of which has been striated in like manner from north to south, seemed to me

long ago to fall into the category of subaqueous striation by floating icebergs, which were here and there arrested in their progress by sunken rocks. When presiding over the Geological Society of London, in 1842, I gave all credit to Mr. Peter Dobson, a citizen of the United States, for the adoption of that view in reference to his native land,—a previous acquaintance with whose writings, I then said, might have saved volumes of disputation on both sides of the Atlantic.* And now, after a lapse of 22 years, I hold to the same belief.

In the admirable work of Sir W. Logan on the 'Geology of Canada,' my eminent friend expresses the opinion, "that the grooves on the surfaces of the rocks which descend under the water appear to point to glacial action as one of the great causes which have produced these depressions."† Not having visited the region myself, I should have no right to oppose my opinion to that of such weighty authority, were it not that the grounds assigned for believing in the excavating power of glaciers in North America are the same striations on the sides of the lakes, and beneath the water, as those which I have cited from the shores of the Bothnian Gulf and the lake of Onega in Northern Russia. Now, as regards the latter countries, I have shown that land glaciers could never have passed over them; for surely no terrestrial glacier in advancing to Finland and Northern Russia can have scooped out the Bothnian Gulf by the way! Instead of such striation on the sides of rock-basins, now filled with water, being proofs of the grinding and excavating action of former glaciers, particularly in the cases of Finland and North America, where no lofty mountains, as in the Alps, are at hand to give great power to descending masses of ice, I conceive that such phenomena can only be explained by appealing to the grating action of the bottom of former floating icebergs. My belief is, that the great North American lakes were cavities originally due to a combination of ruptures and denudations of the rocks, and that the whole surface of the lower country thus prepared, was under the sea when icebergs coming from Arctic glaciers floated over it.

We can thus well imagine how countless icebergs were here and there arrested on those submarine rocks which now form

* See 'Anniversary Address, Proc. Geol. Soc.,' vol. iii. pp. 686 *et ante*.

† 'Report of Geological Survey of Canada, 1863,' p. 889 and note *ib.* Montreal.

the sides of the lakes, and how each icy mass, forced on by a powerful current, after producing the well-known striation on the points of stoppage, would necessarily, when set free, float rapidly across the deep sea cavity, until the base of the iceberg was again arrested by the prominences on the opposite side of the depression, there again to make striations with the stones held fast in its bottom. In this way we can just as easily account for the transport of the numerous great erratics which are spread over North America up to 38° N. latitude, as we have explained the transport of the Scandinavian blocks up to the foot of the Carpathian Mountains.

Whilst, therefore, I fully recognise the stupendous spread and influence of former land-glaciers over extensive regions, I at the same time affirm, that as regards the striation and polishing, the worn side and the abrupt side of the rocks affected, floating icebergs, when impeded by submarine obstacles, have also produced those results. The true and independent test of the action of terrestrial glaciers is the existence of moraines. Now, there is no trace of these peculiar accumulations in the South of Sweden and Finland, all the detritus of those regions, as well as of the North of Russia and Germany, being waterworn; and I have yet to learn that there are any evidences of true moraines in the low countries of Canada and the United States.*

[Whilst I was reading this Address to the Geographers in London, that sound practical geologist, Principal Dawson, was performing a similar duty at the Annual Meeting of the Natural History Society of Montreal. Having received a copy of his Address in time for insertion of a Postscript, I am glad to have the opportunity of stating that he also is a vigorous opponent of the theory which refers the striation of the North American rocks, and the excavation of the great lake basins of that country, to the action of terrestrial glaciers. He shows indeed that the great striation of a large portion of the continent from N. E. to S. W. was from the ocean

* For a full explanation of my views respecting the manner in which former floating icebergs transported blocks, and spread out submarine detritus, I must refer the reader to the 21st and 22nd chapters of the work 'Russia and the Ural Mountains,' pp. 507 to 556. Since that time (1845) I have indeed seen reason to admit a much greater extension of former land-glaciers than my colleagues and myself then believed in, and this I explained in my last Address to the Royal Geographical Society.

to the interior, against the slope of the St. Lawrence valley, thus disposing at once of the glacier theory; for it is impossible to imagine that a glacier travelled from the Atlantic up into the interior. Admitting that in limited tracts of Eastern America there may have been local glaciers, Mr. Dawson believes, as I do, that the rocks of the chief countries in question were striated when the land lay beneath the sea.]

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