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from the author,
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ON

GLACIAL PHENOMENA

IN

SCOTLAND AND PARTS OF ENGLAND.

BY

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*On Glacial Phenomena in Scotland and Parts of England.**

The subject of ancient glacial phenomena having been much before the public a few years ago, I must entreat the Society to believe that I should not have sought their attention to it again, if I had not during the last three years seen reason to believe that it has as yet been but imperfectly presented, and that English geologists in general have arrived at conclusions regarding it which cannot be maintained.

It would detain us too long, and be in a great measure labour thrown away, to renew the combat with those who think that diluvial action in any form is sufficient to account for the phenomena in question. I can scarcely even pause to argue with those who hold that floating ice is the only agent required in the case. If the gentlemen who abide by such doctrines would examine the action of an existing glacier in the Alps, they would find that the effect upon the subjacent rocks is absolutely the same with the appearances of what are called polished and striated surfaces in these islands, where glaciers do not now exist. If they were to travel through Norway and Sweden, they would see such an extent of surface abraded, and an uniformity of striation observed over such large areas, that so light, partial, and irregular an action as that of floating masses of ice would appear totally inadequate to account for the effects. It need scarcely be insisted on, that opponents of theory are as much bound as theorists themselves to observe the ordinary rules of science, —namely, to argue on the unknown from the known, to look more carefully to distinctions than to resemblances, and to give no presumed agent too much to do. Now, I have seen what I consider an ice-polished surface crossed by a small runnel of water carrying minute gravel, and it was clearly observable that where the water crossed, the surface was changed,—became rougher and dimmer, something like the difference between chased and polished goldsmiths' work. I have examined the rocky beds of many mountain streams

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accustomed to bring down all sizes of gravel, but never found in any instance those flowing outlines of abrasion which we see in the so-called glacial surfaces. There is a palpable enough difference, moreover, between the confused masses of mud and sand, mingled with rounded blocks, which are found in connection with polished surfaces, and the sorted materials, gravel, sand, and clay, which are indisputably attributed to watery action. I cannot entertain any doubt that, had these specialties in the respective effects of the two agents been carefully looked to, we should have had much less controversy on this subject, and we should by this time have arrived at results much more satisfactory.

With minds rightly prepared by observation of what ice actually does in the countries where it now works, I could no more expect to see these differences overlooked, than to find in ordinary life men attributing saw-dust to the action of a plane, or chips to the operation of a saw. As for icebergs, they have doubtless played a part, if not in the abrasion of rocks, at least in some of the associated phenomena of the superficial deposits; but to attribute to them the whole phenomena is utterly unwarrantable. If any man were to say, that because he can with some difficulty smooth a rough surface of wood with his thumb-nail, therefore his dining-tables must have been fashioned and polished by the joiner with that little instrument alone, I would consider him as advancing a theory fully as tenable as that which consists in attributing all the so-called glacial phenomena to icebergs. It is really, however, no want of charity to say that much of the opposition to glacial theories arises from an inadequate acquaintance with the phenomena of smoothed rocks and the various deposits laid over them, and an over-faithful attachment to, or misapplication of, certain theories of older date.

Ancient Moraines connected with Corries or small Valleys.

When proofs of ancient glacial action in Scotland were first looked for in 1840 by M. Agassiz and Dr Buckland, a great number of ancient moraines were announced in the middle and southern districts, as well as in the Highlands. There cannot, however, be the least doubt that both of these

observers were misled by the novel features of our superficial formations, and in many instances mistook for results of glacial action what were in reality alluvial accumulations, most of them being those ancient deltas of mountain streams which are so often found where narrow side glens join the principal valleys.

Amongst the contemporary observations of Sir Charles Lyell, two objects are cited, which answer so entirely to the character of ancient terminal moraines that I cannot doubt their being of that character. They occur in the small elevated valleys on the skirts of the Grampians, which contain the Lochs Whorral and Brandy. "Loch Brandy," says Sir Charles, "is surrounded on three sides by lofty precipices of gneiss, while on the south it is bounded only by an enormous accumulation of sand, mud, and fragments of rocks, evidently derived from the cliffs which overhang the lake on the east, north, and west." We only can account for an accumulation of such a kind in such a position by supposing the action of a small local glacier. The two lochs are 1500 feet above the sea. Professor Ramsay has lately discovered lakes in North Wales formed by dams which he believes to be ancient moraines; and Mr Darwin has described similar objects as occurring in South America.

Professor J. D. Forbes's Observations on the Cuchullin Hills, published in 1845, included descriptions of the general glacial phenomena of that district, which are certainly of a most striking character, the whole central valley, in which Loch Coruisk lies, being shaven bare and striated, with a vast number of blocks scattered over the surface, many of them in situations where ice alone could have placed them. Yet it is remarkable that no true moraine exists in this glen; that is to say, no train or ridge of the rough detrital matter marking the sides or skirts of an ancient glacier. Professor Forbes describes one true and unmistakeable moraine as forming "an elongated semi-oval" round the mouth of a deep *corry* on the outside (westward) of the Cuchullin group. He also adverts, in less confident terms, to something of the same kind at the mouth of the Corry-na-briech,—a short abrupt valley, likewise looking outwards to the north-west,—

where, however, I failed to trace any object which realised to my mind the idea of a true moraine. When our associate Mr Maclaren, in 1849, gave us his accurate summary of Glacial Phenomena in Scotland, he justly remarked the *rarity of ancient moraines;* but he next year described to the British Association an object which he thought might prove to be of that kind, which he had found in Glen Messan, a small valley connected with the Holy Loch, on the Firth of Clyde.

Such may be said to be the present posture of this branch of our subject. I have now to enumerate a few ancient moraines which have come under my own attention in Scotland.

To the eastward of the Cuchullin group, and divided from it only by Glen Sligachan, a wild valley full of polished and striated surfaces, is the lofty mountain called Ben-Blaven. A short abrupt valley, called Corry-hashtel, cleaves its south side, terminating at the sea near the farm-house of Camusunary. About half way down this corry, on its west side, commences a long train of blocks, in three separate and distinct lines, followed farther down by three ridges of blocks mingled with mud, forming, beyond all question, the lateral moraines of an ancient glacier which had descended through Corry-hashtel, the outer line being the chronicle of its greatest magnitude, the second marking its limit after it had shrunk, and the third indicating its final condition. Another and still ruder corry, descending the east side of Ben-Blaven, with the lower summit of Garravine on the right, presents at its mouth two or three distinct ridges of blocks mingled with mud, which have evidently been the terminal moraines of a glacier once filling that corry, and which had experienced a similar shrinking. In this corry I found striated rocks.

In the savage alpine district extending along the west coast of Ross and Sutherlandshire, moraines of this kind are not uncommon. Indeed, in most of the high valleys of this desolate tract, we find rude masses of detrital matter which have evidently come, by means of glacial action, from the neighbouring hill sides; but I propose to specify only those which take an unmistakeably moraine form. On the south portion of the lofty old red sandstone hills of Applecross,

there is a short but deep valley issuing upon the road, about three miles from Keeshorn. At the mouth of the valley, and near its rivulet, large spaces of bare rock are polished and striated, the striæ being from N. 30° W., and thus conformable, as is customary, to the major axis of the valley. Round the mouth of this valley are curving ridges forming true moraines.

In the valley in which Applecross House is situated, lumps, lines, and cones of similar detritus, generally bristling with large blocks, are scattered over a wide surface, and I found amongst these one decided set of curving ridges, having the concave of the curve turned in the most significant manner to a deep lofty recess in the side of the glen. These I consider as true moraines, the product of a glacier formed at some remote period in Corry Glas, the recess pointed to.

North of Loch Broom, on the west coast of Ross-shire, is a huge mountain named Ben More Coigach, of a triangular form, and having very precipitous sides. In a deep dark valley to the north of this mountain, a scene of extraordinary sterility and rudeness, I found a striking collection of hummocks and ridges of detrital matter, with some huge blocks perched on the summits of rocky eminences. At one deep precipitous corry towards the east, there was a regular curving ridge of detritus, rough with blocks, having the concave side of the curve turned towards the corry, from which it is not more than a quarter of a mile distant. This I also consider as a true moraine.

In Assynt, Sutherlandshire, the eastern slope of the mountain Canisp extends in a tolerably straight line for several miles from the east end of the loch. At two places there are slight hollows in the line of slope, and *apropos* to these there are moraines in the valley below, filling its breadth of a quarter of a mile, but partially demolished by the rivulet which seeks its way amongst them. In both of the hollows, the white quartz rock is polished, with *striæ* pointed straight down hill, clearly the effect of the glaciers which deposited the moraines. What strikingly affiliates the moraines or detrital ridges to the recesses in Canisp is the fact, that the outermost lines lie close under the *limestone*

cliff on the other side of the valley, but nevertheless contain only masses of quartz derived from Canisp.

The only other detrital phenomenon of the kind here adverted to which I have to mention, is one in Glen Messan, a branch of the greater valley, containing the Holy Loch, in Argyleshire. Not far from the mouth of this glen, close above a place called Coruisk, where another branch glen joins it, there is a lofty mound of detrital matter, smooth in the surface, and covered with turf, forming a sort of barrier across the valley, but leaving an opening at the north extremity, through which runs the little river Messan. This, I suppose, is the moraine which Mr Maclaren introduced to the notice of the British Association in 1850. I do not presume to decide about the actual history of this remarkable and singular object, but would merely remark that some caution will be necessary before deciding that it is the moraine of a glacier which has descended Glen Messan, as, considering its relative situation, and remembering similar objects in the valleys of the Alps, it may be the left lateral moraine of the glacier of the branch glen which issues into Glen Messan close by. However this may be, there is an example of the true moraine in Glen Messan, about the origin of which there can be no mistake. It occurs at a place called Stronlonaig, about three miles above Coruisk. There is here a corry on the south side of the glen, a rude savage recess, enlivened only by a tumbling torrent. In the bottom of the glen, two short lines of moraine matter curve towards the mouth of the corry, but at such a distance that no watery action connected with the corry could account for them. Besides, between the ridges and the mouth of the corry, there is a *talus* of gravel, the separate and characteristic result of such watery action, and evidently of later origin. In short, there has first been a glacier in this corry, descending into Glen Messan, and leaving there two terminal moraines in succession; afterwards, this has passed away, and been succeeded by the present system of things, during which the rivulet has formed a *talus* of debris circumscribed by the inner moraine.

Ancient Glaciers in Limited Mountain Districts.

A short excursion in the Lake District of the North of England in April 1852, satisfied me that that district had been the seat of local glaciers, each of which moved down its respective valley, and I have since found that Mr Maclaren came to the same conclusion from what he observed in the same region in 1850. A few stray glacial phenomena had been previously observed in the district by Dr Buckland, Professor Phillips, Mr Bryce, and others.

Overlooking Skiddaw and Saddleback, which stand comparatively isolated, the mountains of the Lake Country form two or three centres of peculiar elevation, from which the valleys containing the lakes take their origin. The principal centre is at Scafell and Bowfell, from which Borrowdale descends to the north, the valley of Coniston Lake to the south, and Wastdale to the west, while to the south-east descend various minor vales which meet at the head of Grasmere, and are continued in the great valley of Windermere. The vale containing Thirlmere also has its head in this cluster of mountains. Another centre is formed by Kirkstone Fell, Rydal Head, and Helvellyn, whence descend the valley containing Ulleswater on the one hand, and the vales of Rydal and Kent on the other. Between the vales which meet at Grasmere, and that containing Thirlmere, there is a valley of passage, the summit of which at Dunmail Raise is 760 feet above the level of the sea.

In all of these valleys which have been examined by Mr Maclaren and myself, namely Borrowdale, the Ulleswater valley, those of Thirlmere, Grasmere, Windermere, and Kent, we have found unequivocal memorials of ancient glaciers descending in them respectively.

The chief of these memorials are prominent masses of rock by the sides of the valley, presenting rounded and polished surfaces towards its head, with rough faces downwards, the polished surfaces being farther grooved and striated in the direction of the valley, whatever that may be. Rocks so marked are particularly conspicuous near the site of the famous Bowderstone in Borrowdale. The lofty hummock on

which that large mass has fallen from its parent cliff above, is itself partially abraded and smoothed by ancient ice. Various prominent masses at Lodore, at Grange, and on the west side of Derwentwater Lake, are in the same condition, none, however, so strikingly so as a platform of flat bare rock near the bridge at Grange, extending to the length of forty-two paces, and still retaining its original glassy polish and striation, notwithstanding its being subject to much wearing, in consequence of its proximity to a public road and to a farm-house. About a mile above this point, the extensive basin, embraced by the arms of Scafell and Bowfell, and which must have formed the gathering place of the snow forming the glacier of this valley, contracts into a comparatively narrow space, and there the polished surfaces are particularly conspicuous. Just above the point of contraction, these polished surfaces are slightly roughened, and bare masses of partially water-worn materials laid against them. I was at a loss to account for these facts, as the rivulet runs through a rocky channel forty or fifty feet below, until I observed that the passage for the river is through a chasm, the sides of which, angular and rough, are altogether in contrast to the neighbouring polished surfaces. It clearly appears, that, before the river had cut out this channel, it had formed a lake in the open valley above, and that to the action of this lake we are to attribute the slight roughening of the previously glacialised surfaces, and the accumulation of water-worn debris.

The abraded surfaces at Patterdale, in the Ulleswater valley, are scarcely less remarkable. Near the inn at the head of the lake, there is so much of this sterile surface presented, that the place reminded me much of certain parts of Sweden. The two partially-wooded islets near the head of the lake, rounded, shaven, polished, and only admitting vegetation in chinks, are exactly like the numberless *roches montonnées* which gem the Christiania-fiord, and, indeed, the whole of the sea-board of Norway. As in the case of Borrowdale, there is an extensive basin suitable for the collection of snow at the head of this valley, and hence we might expect a glacier of considerable magnitude. My observing glacialised surfaces fully 200

feet above the lake is not, therefore, surprising. Mr Maclaren speaks of a striated *vertical* face of rock on the west side of the deep narrow valley of Troutbeck, 500 feet above the bottom of that valley, indicating a glacier of still greater depth.

In the Thirlmere valley, for several miles down from the summit at Dunmail Raise, I could find no glacialised surfaces; but at length they became conspicuous at a place opposite Armboth, near the lower extremity of the lake. Between this place and Keswick, four miles from that town, I found a considerable surface, exposed in consequence of quarrying for road-metal. The whole was beautifully polished and striated, the direction of the striæ being a little west of magnetic north, and thus coincident with the major axis of the valley. In all of these cases, there are unequivocal appearances of a *stoss seite*, or exposed side to the south, or up the valley.

For some miles below Dunmail Raise, in the Grasmere valley, there are, in like manner, no abraded surfaces; but they present themselves on the north side of that lake, with striation pointing to N. 25° W., being the direction of the valley at that place; likewise in a low field south of Rydal, and in Dr Davy's garden, near Ambleside, where the direction, however, of the striæ is more easterly, and towards Rydal glen. On the high ground over which the bye-road passes between Grasmere and Skelwith Bridge, there are mammillated rocks, with striæ from N. 25° W., or nearly magnetic north, a direction from which it would be difficult for any such agent to come to such a place. At Birthwaite Railway Station, near the shore of Windermere, there is a large recently exposed surface, glacially polished, and bearing striæ of the same direction, being that of the valley of Windermere.

In the valley of the Kent, near Stavely, there are several examples of abraded surfaces, one of which has been accurately described by Mr Bryce. It is situated at a place called Jacob's Wood, and having only lately been exposed, it is in the finest possible condition. The slate (Lower Ludlow rocks) is here remarkably hard, insomuch that an attempt at quarrying it has had to be abandoned. A surface, fifty-three

feet long by fifteen broad, is laid bare by the removal of a coarse brown detritus containing boulders. It presents four bosses, side by side, in the direction of the length, and the whole is beautifully polished, with finely-marked striation across the planes of stratification, being in the direction of N. 46° W., [Mr Bryce says N. 34° W.,] thus pointing towards the eminence forming the west side of the upper and more mountainous portion of the Kent valley.

A detritus of half-worn blocks mixed up with a brown mass of clay and sand, precisely resembling the moraine matter left at the sides and extremities of existing glaciers, is deposited in various parts of the Lake valleys, in immediate contact with the polished surfaces, and generally in the lee of eminences. It is generally where such matter has been excavated for the making and repairing of roads, that we find the best examples of polished surfaces, the detritus having served as a complete protection to the vitreous polish left by the abrading agent. As far as I have observed, the superficial matters do not anywhere, in the central parts of the Lake District, present the peculiar forms of either lateral or terminal moraines, except in one instance, in the Thirlmere valley, near its head at Dunmail Raise. There, in the angle between a side valley and the principal one, we find a long ridge of rough detritus with many large blocks, extending down the hill-face. An inexperienced observer would be at a loss to understand the relations in which such an object could stand towards any imaginable glacier hereabouts; but one who has seen the moraines of the Glacier des Bois and the Glacier d'Argentière in the Chamouni valley, would quickly perceive that this, in reality, is the right lateral moraine of the glacier which issued at this place into the Thirlmere valley, from one of the high glens which ascend into the mountain chain of Bowfell. Mr Maclaren's moraine in Glen Messan has been surmised as an object of precisely similar history.

Not far from the moraine just described, on the summit called Dunmail Raise, which is a valley of passage between two ordinary valleys, there is a great mass of detrital matter, through which the infant rills of the district have made deep

passages, shewing the hugeness of the deposit. I regret that I did not examine this mass very carefully; but I am satisfied that it is a different kind of detritus from the brown moraine matter already described, most probably the blue boulder clay. It is very remarkable to find a different detritus in a situation obviously out of the reach of the glaciers of the valley system here described.

Dr Buckland, in 1840, announced objects in the vicinity of the lake country, which he believed to be moraines connected with its valleys. Thus he traced the spoils of the Patterdale and Ulleswater valley in "extensive moraines loaded with enormous blocks of porphyry and slate," in the vicinity of Penrith. At the vomitories of Long Sleddale and the Kentmere valley, he found "large and lofty piles of gravel." The districts of Furness, Ulverstone, and Dalton, to the south of the lake region, he described as "extensively covered with deep deposits of glacier origin." Dr Buckland had not been able to examine the western outskirts of the districts; but he believed that many hillocks laid down there in masses were remains of moraines. Seeing that the learned geologist, in the novelty of the investigation, mistook some alluvial accumulations in Scotland for ancient moraines, I cannot bring forward these observations as conclusive upon the subject; and I must regret that I have not been able to contribute any of my own. Now, however, that the valleys are known to have been filled by glaciers, it may be hoped that some local observers will institute an inquiry to ascertain whether their detrital spoils remain in definite forms at their vomitories, or have been carried away and dissipated over the neighbouring country.

From the whole phenomena, I infer that the lake country has at one time been the seat of a radiating system of glaciers. I regard it as a complete and well-defined example of *glacial action in a limited mountainous district*, where the direction and slope of the valleys clearly determine the ice-streams. It is easy to see how the spacious basins of elevated ground embosomed amongst the heights of Scafell and Bowfell on the one hand, and Helvellyn, Rydal Head, and Kirkstonefell on the other, formed the *berceaux* of the vari-

ous glaciers of whose course we have described the memorials. And as such basins are necessary for the formation of glaciers, we can readily understand why no traces of glaciation are to be found in the higher parts of the valleys meeting at Dunmail Raise, as also why a mass of peculiar detritus is left there. That place had been out of the scope of the glaciers here spoken of, and its mass of detritus may be regarded as probably the result of some earlier operations.

From the descriptions which have been given us of the Snowdonian regions in North Wales by Dr Buckland, Mr Darwin, Professor Ramsay, and others, and from what I have seen of it myself, I entertain no doubt that it is another example of a *limited mountain district once occupied by local glaciers*. Seven valleys radiating from a centre of elevation present, along their sides and bottoms, rock faces which have been ground, smoothed, and striated by ice, the striæ being in each case parallel to the line of the valley. There are also in and about these valleys certain detrital masses which have been set down by several observers as the moraines connected with their ancient glaciers; but my own observations lead me to consider some of these as deficient in the characteristic form of moraines, and, as a general rule, the Snowdonian valleys may be said to be remarkably bare of detrital matter. While this is the case, the outer flanks of this group of mountains, and many high table-lands interspersed amongst them, are covered deeply with the "Northern Drift." That this, however, is the product of a different condition of things, and of an earlier epoch than that of the valley glaciers, appears to me proved by two facts, namely, that the connection of the sea with the origin of the drift is indicated by the shell deposits found in it, and that, as we learn from a late paper of Professor Ramsay, "small patches of it alone remain nestled amid the smaller bottoms of the hills." It hence appears that the glaciers have removed or swept out this drift from the valleys, while failing to disturb it on the high grounds and the outskirts of the mountain district. Mr Ramsay, with his usual acumen, has drawn this distinction, the importance of which will appear in a stronger light before we have done with the subject.

In Scotland, the mountain systems are too large to allow of our seeing any such well-defined examples of what may be called District Glaciation, as those cited from South Britain. The memorials of the action of ancient ice are, as is well known, abundant in our land of mountain and flood; and we shall presently endeavour to embrace them in a comprehensive sketch; but I am unable to select any particular district precisely comparable to the Lake country or the Snowdonian region, although, as has been seen, there are in various places proofs of still more narrowly local glaciation. It is, also, to be remarked that there are in several district valleys in Scotland, proofs of local glaciation on a larger scale than those already mentioned; but these I shall advert to in the comprehensive sketch which must now be attempted.

Proofs of a more General Glaciation in Scotland.

The examples of smoothed and striated rocks in Scotland, known up to 1849, were summed in an interesting paper by Mr Maclaren, read before this Society in April of that year. They were very numerous. He redescribed the remarkable example in Gairloch, originally discovered by himself in 1845. Instances were also cited from the neighbouring valleys of Loch Long, Loch Eck, and Loch Fyne; the direction of striæ being in all instances conformable to the direction of the valleys, namely, in the first three cases from NNW., and in the last NNE. Mr Maclaren described striated rocks in the valleys of Loch Earn and Loch Katrine, striæ directed from the west; along Loch Lubnaig, directed from the north; along the skirts of Demyat hill, and at Torwood, in the valley of the Forth, pointing from WNW.; and at numerous places in the lower parts of the valley of the Forth, about Edinburgh, and on the Pentland Hills, pointing generally from WSW. Our learned associate also adduced examples of the same phenomena, from the east end of Loch Awe in Argyleshire, from Loch Etive near Oban, from Loch Leven at Ballachulish, and from Glen Spean near Fort William, where the exposed sides were clearly towards the east, and the smoothing agent had of

course a westerly direction. He, therefore, drew the inference that "the nucleus of this physical force, the common centre from which their agents moved, was in the group of mountains extending from Loch Goil northward to Loch Laggan, dividing the springs of the Spean, the Leven, and the Orchay, from those of the Spey, the Tay, the Earn, and the Forth." At the same time, Mr Maclaren candidly admitted that much remained to be done before adequate materials for a satisfactory theory were collected.

M. Charles Martins, in 1850, supported Mr Maclaren in his view of glaciers radiating out of the Highlands, and descending on the plains, as sufficient to produce the phenomena which are to be accounted for.

It seems, nevertheless, that both Mr Maclaren and M. Martins were aware of some features of the case which such a theory could not well account for. Mr Maclaren had himself discovered that the eminence between Loch Long and the Gairloch, 600 feet high, was as perfectly smoothed along the top, as was the bottom of either of the two valleys. Another even more startling fact, was that of a summit of the Pentlands, 1400 feet high, where Professor Fleming had found striæ identical in direction with those in the plains to the northward. Mr Maclaren had likewise observed in the valley of Westwater, which runs north and south at the western extremity of the Pentland range, near Dunsyre, and which is 800 or 900 feet above the sea, that striæ *crossed through it* in a direction from west to east, thus persevering in the normal direction of the district, in circumstances where, if anywhere, a divergence was to be expected. That any group of our Highland mountains, ranging as they do from 3000 to 3500 feet high, should have sent forth from their valleys, ranging far below that elevation, for so it must have been, a glacier which reached the area of Mid-Lothian, seventy miles off, in such volume and depth as to envelope a range of hills to the depth of 1400 feet, and in such unyielding force as there to cross a minor valley, 800 or 900 feet above the sea, without diverging in the least from its course, was certainly to be scarce expected by any one who was content to confine his view to what we see done by such ice-

streams as now exist in the Alps. I, in some measure, intimated this objection to the British Association in 1850, when, professing to be unprepared for any theory on the subject, I held that one was wanting which would plausibly account for the Pentland phenomena, as also for the uniformity of striation on the front of the Fife hills, on the opposite side of the Forth valley, for I had been shewn markings at Cullelo quarry and near Burntisland, identical in direction with the various examples in Lothian, proving that the whole valley from the Lomonds to the Pentlands, and even beyond these hills, had been under one glacial agent, self-consistent throughout in its movement and operation.

The observations which I have been able to make since the Edinburgh meeting of the Association have served much to confirm me in the belief, that the views entertained up to that time, for the explanation of the glacial phenomena of Scotland, were far from being adequate to embrace the facts of the case.

It appears to me that previous observers have, in the first place, had too few facts to speculate upon, and have consequently pronounced as if certain local and partial phenomena, such as might arise in a limited Alpine region, were alone to be accounted for. They have also, from a similar limitedness of view, erred in attempting to explain the phenomena as a product of only one set of conditions existing at one point in time.

As to the real extent of the phenomena in Scotland, the difficulty is not so much to say where there *are* abraded and striated rocks, more or less covered by glacial detritus, as where such rocks *are not*. I have, since August 1850, found them along the whole range of the coast north of Argyleshire, namely, in Inverness-shire, and the counties of Ross, Sutherland, and Caithness. I have found them in the Isle of Skye, in situations independent of the Cuchullin Hills : in the island of Mull ; all along Loch Lomond, and Loch Katrine ; even the picturesque eminences which constitute the Trosachs being *roches moutonnées*, with abraded faces to the west. I have likewise found them in Perthshire, Fife, and Aberdeenshire. They are reported from Ayrshire. I have found a large lateral

moraine near Maxwellton House, in Kirkcudbright, and seen fine smoothings with striation on the surface of Corncockle Muir, in Dumfriesshire. When we add these situations to those previously ascertained, we see that glacial phenomena are so widely distributed, that it is making but a small demand on hypothesis to say, that we should find traces of ice everywhere, except at the utmost on the summits of the loftier hills, if all our rock-surfaces were exposed, and if all those actually exposed had been equally capable of retaining the impressions made by ice. In point of fact, we may see in every valley in the country, forms of the surface which, though changed by weathering and other agencies, it is easy to connect through a series of similar objects with indubitable glacial surfaces, so as to satisfy ourselves that these too have been glacialised. Thus, nothing is more common in the Highland valleys than rounded humps of upturned gneiss or mica-slate, with the strata shorn sharply through. In many instances, exposure has caused a weathering, the extent of which we may know to be one, two, or even three inches, by the prominence of quartz veins to that height. Near these, we often find, where a recent exposure has taken place, surfaces of the same rock, finely smoothed and striated. Other examples in all intermediate degrees of weathering can be detected, clearly shewing that the polished condition was originally that of all such rounded masses. Hence, even when there is a single case decided of polishing in a whole glen, we may see enough to prove that such was the original condition of the whole. So also, if we find sandstone of a certain considerable degree of hardness always presented prominently above the surface, as at Ravelston and Craigleith, in Mid Lothian, at Cullelo in Fife, and at Brora in Sutherlandshire, and always in these instances smoothed and striated even after long exposure, we may not unreasonably infer that other sandstone surfaces, in no respect of relative situation different, but comparatively soft, and tending to a blazy condition of the surface, would have been glacialised likewise, if of the proper consistence.

As our own neighbourhood is specially rich in the pheno-

mena of polished and striated surfaces, I may dwell a little longer upon it, mentioning a few examples as yet unrecorded.

There are, as is well known, some vertical faces of the basaltic clinkstone of Edinburgh Castle rock, which have evidently been polished by some external application. Near this, in the foundation of the Corn Exchange in the Grassmarket, Mr David Page found the subjacent rock polished and striated. It is well remembered that, a few years ago, on the cutting out of the superficial detritus on the south shoulder of Arthur's Seat, above Sampson's Ribs, a spot 390 feet above the sea, the rock was found to form a kind of trough, the sides and bottom of which were polished and striated. In 1850, some cuttings at the St Margaret's station of the North British Railway, near Jock's Lodge, enabled me to ascertain that the north base of Arthur's Seat is smoothed and marked in precisely the same manner, namely, with striæ and groovings directed from a point south of west; while numerous rounded and striated boulders are interspersed through the superincumbent compact blue clay, There has lately been a similar exposure of the surface at the parting of the Bathgate and Edinburgh and Glasgow Railways at Ratho, and there likewise we see the rock polished and furrowed, while the striæ observe a similar direction. In East Lothian, I have found at Whitekirk, at Craig, at Fenton Town, and other places, instances of this phenomenon, additional to those previously detected in that county. Professor Fleming likewise detected glacial surfaces on the west front of North Berwick Law, near the base. The direction of the lines is generally very nearly uniform, namely, from one to two points south of west, being the general direction of the valley.

There is something in the general configuration of our district even more remarkable than in these polished surfaces. It is forty years since Sir James Hall observed the peculiar form of eminence which he called *crag-and-tail*, and of which he pointed out instances in the Abbey Craig and Stirling Castle rocks, in the hill of the Old Town of Edinburgh, and some others. It consisted, as is well known, of an abrupt

face or cliff to the westward and a gentle slope to the eastward, the face being usually composed of some rock capable of presenting a powerful resistance to any denuding agent. Colonel Imrie found in the Campsie Hills and the Grampians a marked tendency to the same form, with the same arrangement. More than this, but quite in conformity with it, is a tendency in the surface of Lothian to a *ridge-and-trough* form, exemplified most strikingly in such groups of third-rate hills as those of Dalmahoy and Garleton, where the lines of both the heights and hollows are throughout very nearly the same. We see the same form on a subdued scale in the ground between Corstorphine Hill and Leith, which consists of a series of broad longitudinal swells, with slight hollows between. All of these ridges and hollows are in the same direction as the hills of crag-and-tail, and the whole conform to the direction of the striæ upon the rocks.

From such objects, it is but a step to extend our observations to the sides of those larger hills which bound valleys, as the Fife Lomonds and the Pentlands, where we very often find a remarkable form of surface, which may be described as *Mouldings*, extending longitudinally, but not always quite horizontally, along the slope, and clear in their cross sections of every kind of abruptness or inequality rising above the sectional outlines. Such mouldings are easily seen on the Pentlands from about Colinton; on the northern aspects of Arthur's Seat; under Dunearn summit in Fife; on Demyat from the valley below; on several parts of the Campsie Fells, particularly above Banton; on the hills to the south of Loch Vennachar and Loch Achray, in Perthshire; and on many other of the Scottish hills, but generally most clearly when the sun shines at a low angle along the slope. They are clearly attributable to the operation of the same agent, of which some other serrations or irregularities have fashioned the longitudinal ridges in the valley below; that is to say, more correctly, some stronger consistency of rock has in both cases presented a more than usual resistance to the planing agent. Now these markings are seen at great elevations among the hills, and but a small way from their summits; and the flowing sky-lines of the greater portion of our secondary hills are

manifestly connected with them in respect of cause. Thus, when we eliminate cliffs and other rough parts as only exceptions, and the effect of subsequent weathering and other casual forces, a comprehensive eye cast over the mountain system of Scotland, has no difficulty in seeing the effects of a general abrading agent which has passed over and more or less moulded nearly the whole.

I am prepared, however, to shew proofs of a general abrasion in Scotland, compared to which the above can only be considered as adjuvant and subordinate.

Most students of geology will remember the striking description which Dr M'Culloch gives of the range of old red sandstone mountains which extends for fifty miles along the west coast of Ross and Sutherland. From a platform of upturned gneiss, undulating in outline, and between 200 or 300 and 1000 feet above the sea, rise these mountains isolatedly to the height of from 3000 to 3500 feet above the sea, with wide spaces between, in some of which lie lakes and estuaries. The strata being disposed at a low angle, it becomes evident that they are the relics of one wide-spread formation, out of which gaps have been cut by some external agent; and hitherto the district has been regarded as a striking example of the process of denudation, and often adverted to as such in elementary books, the agent usually presumed being water. Not one of these mountains, as far as I am aware, advances to the coast or abuts on the sea; but at Rhu Stor, in Sutherlandshire, a small low patch of the sandstone borders the coast and passes beneath the waves, which have cut it into very fantastic forms.

It seems to me entirely inadmissible that the sea has been the denuding agent in this case, and for the following reasons: —*First*, On the gneiss platform between the mountains and the coast, we do not see the fragments of sandstone which would be deposited there by such an operation. *Second*, We have at Holborn Head, in Caithness, and all along the coasts of Aberdeen and Forfarshire, cliffs of old red sandstone abutting on the waves, and worn by them into deep chasms and caves, with isolated columnar masses here and there left out

at sea; but the faces of the mountains in question bear no trace of such operations.

On these mountains, however, at least such of them as I have examined in the district of Assynt and at Loch Maree in Ross-shire, and on the gneissic platform whereon they rest, there are abundant traces of glacial action. These are apt at first to appear of a confused and contradictory character; but all difficulty vanishes when we arrive at the idea of a local system of glaciers succeeding a system of things during which a more general glaciation took place, and substituting for the effects of that more general movement effects of its own; the key to much that has been perplexing in the investigation of this subject.

There is one of these mountains which attracts more observation than any other, on account of its extraordinary form, which has given it among sailors the name of Sugar Loaf, though it is properly called Suilvean (meaning *Ear Hill*). It extends in a narrow ridgy form for upwards of a mile, with sides so steep as to be inaccessible in most places (I measured an angle of 58° on one side, and found the precipice on the other absolutely vertical); the west end being also very steep, while the east slopes away in a tail. Seen at the west end, the hill looks like a lofty tower with a dome-shaped top, something not unlike the Eddystone Lighthouse,—a resemblance not a little helped by the palpable stratification, which has the appearance of a Titanic masonry. Another perfectly isolated mountain, called Stack, precisely resembles Suilvean, and these, from their position, may be considered as a front guard for the series towards the sea.

Behind that range is a series composed of Cuineag, Canisp, Coul More, and Coul Beg, which, with bold faces to the west, dip down on the east at an angle of about 9°, their lower slopes in that direction passing under another range of hills resting on a broad band of limestone. The backs or eastern slopes of all these hills are composed of quartz rock—sandstone metamorphosed into that character—and the bareness and whiteness of that peculiar surfacing gives them a very remarkable appearance. It becomes readily apparent that

these quartz *carapaces*, as they may be called, are what has protected the hills from the utter demolition and removal which have befallen the matter once filling the great intervals between them.

Now, in this range of hills, there are phenomena of smoothing, striation, and detrital accumulations, which can only be accounted for on the supposition of there having been, besides a district glaciation in the valleys, like that of the Lake Country, *an earlier general glaciation* which has passed over the backs, if not the very summits of the hills.

The valley in which Loch Assynt lies, extending up into a spacious *bosom* of high ground inclosed by the summits of Ben Uie and Glasvean, has been the seat of a glacier originating in that bosom, and which had swept out to sea at Loch Inver and Rhu Stor. We see all along this course, smoothed rocks, with striæ in the line of the valley. In the higher parts, are moraines, one of them forming the barrier of a little lake. In the middle part, about Loch Assynt, are accumulations of moraine matter: while along the gneissic platform, towards Rhu Stor, are examples of long ridges, with the *stoss seite* to the east, and a lee side to west, attended by gatherings of moraine matter in the lee, containing, with many masses of the gneiss, some of the red sandstone, which may be presumed to have been brought from the skirts of Cuineag. When we go onward to the low patch of sandstone on the coast at Stor, we find fragments of the gneiss carried over it, still confirming a westerly movement at this place.

At the back or north side of the elevated ridge formed by Ben Uie and Glasvean, there is another valley called Glen Coul, which runs out to the westward, and is partly filled by the estuary of Kyle Skou. This has likewise been the seat of a local glacier, as appears from similar proofs; but it has been on a smaller scale, not having had such a spacious field for the collection of the proper material.

So much for the glaciation of this district, where there are bosoms amongst the hills and valleys running out from them, appropriate seats of local glaciers. But on the summits and high slopes of the hills, and on the portions of the gneissic

platform not connected with valleys, there are traces of an independent and, I believe, earlier glaciation. On Cuineag and Canisp—on the former up to the height of 1700 or 1800 feet, and on the latter not much less, the quartz surfaces are marked with *black streakings*, which are the striæ peculiar to a singularly hard rock, and these run from about N. 60° W. with certain exceptions. One of these is at the base of the slope of Cuineag, where the streaks are from the direct north, apparently by reason of the turn which the agent has there received from the base of the adjacent hill. Another exception is at the hollow dividing the mass of the hill from its loftiest top, where another system of streakings comes in from the direct west, thus with the other set clipping the summit of the hill. It may be remarked that the dip of the strata on the backs of these hills is usually at a somewhat greater inclination than the outline of the surface, the resistance having been the stronger the nearer the bottom. There is a great quantity of quartz slabs strewed along the back of the hill, being the last fragments which have been torn up by the denuding agent, and many of the surfaces exposed have evidently undergone no attrition. This has afforded us an opportunity of observing the difference between an abraded surface and one which has undergone no abrasion, and it is very striking. The unabraded surface presents an inequality of outline, partaking of a tuberculated character, which is entirely wanting in one which has been subjected to the striating agent.

On a summit running south from Ben More, fully 1500 feet high, and four or five miles to the south-east of Cuineag, there are streakings on the quartz, observing the normal direction of this general movement, namely, about N. 60° W. What is most curious and significant, and settles the question of two systems and epochs of glaciation, is, the fact of there being upon Canisp, cross striæ connected with those local moraines at the base which were adverted to in the earlier part of this paper. The strong normal streaks athwart the hill from the north-west, a direction in which no local or limited mass of ice could move, are clearly chequered with fainter streaks produced by this simple down-hill movement, which

happens to be from WSW. It may also be remarked that, on some other parts of the mountain, of no great elevation, there are down-hill streakings without any of those from the north-west. Such is likewise the case on the back of Coul More.

On the gneissic platform, between Coul More and Suilvean I found polished surfaces, striated from NW. to W.; and to the west and north of the latter mountain are markings in all respects similar. Such is the line of the major axis of Suilvean itself, and of many ridges and hollows of the gneiss, as may be partly observed from the Map; for such is the direction of many lakes which repose in these hollows, and which are laid down in maps. These are situations where no local glaciers could exist. They only could be marked by some glaciation more general than any we now see in operation.

At a particular stage in the investigation of this district, I thought that, there being proofs of so extensive a denudation in Assynt, by an abrading agent coming from the north-west, we ought to find extensive deposits of the detritus of the district in regions situated to the eastward. I therefore made an extensive detour, in order to pass along the valley containing Loch Shin, and looked carefully there for fragments of quartz and old red sandstone. Not a fragment was to be found. The mystery was, however, soon cleared up; for it became evident, from both striated surfaces and moraines, that this valley had been, like that of Loch Assynt and Glen Coul, the seat of a comparatively late local glacier, which necessarily had swept out every particle of earlier detritus.

It must now be observed, that the proofs of such a general extension and so deep a volume of mobile ice, are not confined to this district. Streaking, precisely the same as that of Cuineag and Canisp, exists at an elevation of at least 2000 feet, on the similar quartz mountain named Ben-Eay, south of Loch Maree, and forty miles from Assynt,—this striation being from NW., or thereabouts, and totally irrespective of the form of the hill. On free ground, between Gairloch and Poolewe, there is similar marking, with a direction from WNW. So also is there in the great elevated valley of

passage across the island in Ross-shire,—the dreary Dirry More.

It seems to me that the whole phenomena can only be accounted for, by our supposing that there was, *first*, a general sweeping of the surface of this district by a deep flow of mobile ice, one great cause, if not the principal, of that enormous denudation which has been described, but of which the spoils, from the universality and power of the agent, were in a great measure carried away. *Second*, local, and certainly subærial glaciers, occupying certain valleys in the more elevated mountain systems, and producing moraines, composed of brown clay, sand, and blocks. The small glaciers first pointed to in this paper were perhaps of a still later date, when the mean temperature was not much below its present point.

The examples which have been cited do not, after all, refer to a very extensive district; but when we take a wider range of observation, we find phenomena which are for the most part in perfect harmony with those of the west coast of Assynt. Passing northward to Rhiconich, we find near that place striæ coming in from the coast, from the north-west, and passing across a high moor, with no regard whatever to the inequalities of the ground. A little farther north, at Loch Laxford, a fine surface is marked with striation from the north-west, being *across the valley in which it occurs*. At an opening in the bold gneissic coast which looks out upon the Pentland Firth, there is strong marking in a direction from NNW. The high desolate tract called Moen, between Loch Eribol and Tongue Bay, where there is nothing that could restrain or guide the movement of the ice, exhibits striation from N. 28° W. Striæ, in nearly the same direction, namely, N. 25° W., occur four miles to the east of Tongue Bay. On perfectly free ground, at Armadale, the markings point almost directly from the north. When we pass on to Caithness, where the country generally is of that rounded undulating character which speaks of glacial action, we find a few traces of striation, still from points between north and north-west, which is *directly transverse to a line pointing to the neighbouring hills*. At the Clynelish quarry, near Brora, in Sutherlandshire, the fine surface of smoothed

sandstone, pointed out by Sir Roderick Murchison, exhibits striation from a point north of west. This pointing back to a valley out of which a local glacier may have come, and the gorge of which shews many moraine-like ridges, is perhaps not a true case; but if it be, the line of the striation is not much out of conformity. Striation of north-westerly direction is found in a valley near Loch Fleet, also at Invershin, and along the road to Assynt. So also is it found in the valley of the Shin, but with what I consider undoubted moraines, shewing at least a subsequent local glaciation.

I found only one example of remarkable divergence in Sutherlandshire, beyond the instances of undoubted local glaciation in Assynt, and this was in the valley in which Loch Eribol lies. The sides of this valley are composed of quartz rock, and the whole bears a great resemblance to the Gairloch. The quartz is everywhere smoothed down to a condition of the highest polish, excepting where some modern fracturing has taken place; and the striæ on this fine surface run between a point east of north, and one west of south, being precisely the direction of the valley. The probability is, however, that a glacier has descended this valley from the bosoms of the great eminences in the Dearrie Forest.

Far to the south of this district, in the valleys near the western extremity of the Great Glen, we have seen that there are markings, which Mr Maclaren has described as having a direction from the interior of the country towards the west coast; in which respect they differ from those now under our immediate notice. He particularly mentions some on the south side of Loch Awe, about a mile west from Dalmally Inn, where there are two small *crag-and-tail* hills, with striæ from ENE., and masses of stones and soil to the WSW. He also lays much force upon certain smoothings at and near Monessie, in Glen Spean, where the rough or protected sides are clearly down the valley, or to the west. Now, in several places connected with this valley, there are abraded rocks, with the rough sides in the opposite direction. Mr Milne Home has described one group at the opening of Loch Treig, and another at the junction of Glen Fintec with Glen Gluoy. I was with Mr Milne Home when these examples

were discovered, and can testify to their genuineness. I also find, among my own memoranda, a note and sketch of another, which we had discovered at the head of Glen Glaster, with the smoothed side to the north-westward. Thus, in the very district containing the markings which Mr Maclaren, M. Martins, and Sir Roderick Murchison, have depended on as completing their proofs of a radiating arrangement, we see that there is a more widely-spread set of markings, more elevated in situation, and in conformity with the normal direction. Mr Maclaren also mentions smoothed rocks on Loch Etive, with striation, to his surprise, not conformable to the shore, and coming, as he thought, from ESE., or from Loch Awe, though hills of from 300 to 500 feet intervene. I have no doubt that if Mr Maclaren had seen the examples which exist in the far north, he would have regarded this as an example of that early general glaciation proceeding from the north-west, which we have shewn to be independent of even more considerable inequalities of ground than the hills of Loch Etive.

It happens that, at a place not many miles from Loch Etive, namely the Isle of Kerrera, opposite Oban, there are numerous smoothed surfaces dipping into the sea, with striation from N. 60° W., being nearly the same direction as Mr Maclaren's, WNW. If the agent moved on to S. 60° E., it would strike the shore at Oban; and if it went straight on, it must have passed over the high grounds which lie between that shore and Loch Awe. The question may arise, Did it not pass in the opposite direction? One circumstance, not easily reconcileable with that idea, and otherwise highly curious, is, that on the high grounds above Tobermory, in Mull, twenty-five miles from Oban, there are striæ pointing from N. 60° W. No glacier proceeding from the hills above Oban could go straight on to this point, and leave marks on a hill two hundred feet high. But, when we see marks in the far north, as independent of unequal ground, and equally irrelative to the kind of grounds which feed glaciers, we have no room to doubt that these Mull and Oban markings belong to the same class.

The examples in the valleys of Loch Fine, Loch Eck, Loch Long, and Gairloch, which Mr Maclaren has cited, all with

a southerly direction, may easily be interpreted as parts of this grand early system of glaciation, though perhaps partially affected by local glaciation at a later period. It has already been stated by Sir Roderick Murchison, that there is no imaginable centre for the issue of glaciers of the ordinary kind down the Gairloch. And the objection is one which apparently cannot be answered. Mr Maclaren has himself observed a fact irreconcileable with such a theory in the smoothing of the hills of 600 feet high, between Gairloch and Loch Long. I have myself observed, in the adjacent Holy Loch, that the striation, which is there from north to south, indicates an agent which has come slanting over the hill, between that valley and Loch Long,—an eminence of not less height.

Conformable also are the eastward markings of Strathearn, and the southward markings of Loch Lubnaig. I have lately observed that the valley of Loch Lomond is glacialised southwardly, the line of its length, *roches montonnées*, with striation, being conspicuous at Bealmaha, Rowandernnan, Luss, and Tarbert. Some islets near Luss are of this character, being precisely like the examples in Ulleswater. Those who are accustomed to affiliate glaciers exclusively to high mountains, would be somewhat surprised to see proofs of such a stream of ice having swept *laterally* along the base of Ben Lomond. At the same time, I am not sure that the valley of Loch Lomond has not been latterly filled with a local glacier descending from some of the elevated basins near its northern extremity, and which, by one of its moraines, may have formed the dam at its foot. A train of granite blocks traced by Mr Hopkins along the side of the loch to a northerly origin is a circumstance pleading strongly for such a theory.

One example of smoothed and striated rocks at Stronachlachar, near the head of Loch Katrine, is worthy of particular notice, as utterly destructive of the idea of exclusively local glaciers, and only to be explained by that of an agent wide-spread over the land, plastic, but pressing hard, and not readily yielding to any local obstruction. There is here striation ascending obliquely out of the loch, passing over a high jutting hill promontory, reappearing under compact clay, in low ground, at some distance from the loch, and every-

where maintaining precisely one direction, and that from NNW. To all appearance, the agent which produced these impressions came over a lofty range of hills from Balquidder, and passed on to cross a scarcely lower range, and descend into the valley of Loch Ard. There has also been, as already mentioned, an issue of glaciers by the south-east end of the lake, among the defiles of the Trosachs, part of the roughness of which is caused by a large moraine.

The descent of this great or general glacier into the south and east of Scotland can be traced at other points. A lofty and extensive sandstone plateau between Campsie and Glasgow, exhibits extensive smoothings, with striation from WNW. Eminences of trap in the valley of Strathblane have manifestly abraded faces to the north-west. There are clear marks of the passage of ice over the conglomerate skirts of Demyat, directed to ESE.; also, in the same direction over the sandstone at the Torwood, near Larbert. The line of the remarkable passages through the trap eminence at Stirling Castle is precisely conformable. Farther on, the agent gets a turn to the northward, bringing it into conformity with the line of the Forth valley; it continues to be from about W. 15° S., all along by Edinburgh and East Lothian, the only remarkable excess in this twist of movement being at Silvermine quarry, a lofty position to the south of Linlithgow, where it is as much as W. 45° S. On the lime stone here, over beautifully marked surfaces, lies a deep bed of the compact blue clay with blocks, which, besides being scattered through the mass, form a *zone* a good many feet down, a striking but not unexampled peculiarity.

From the south of the Pentland Hills and Lammermuir range, there are no reported examples of abraded or scratched surfaces, a fact apparently to be attributed to the splintery character of the Silurian hills of the south of Scotland. The general mammillated character of the outline of these hills is, however, very remarkable, from its resemblance to the configuration of ground on which we trace true ice markings. It is also to be noted that in Berwickshire, the masses inclosed in the boulder clay are from the west.*

* Mr D. Milne on Parallel Roads of Lochaber.

The views here advanced for a general glaciation are supported by facts from Scandinavia, which no theory of exclusively local glaciation, or of abrasion exclusively by floating ice, can possibly account for. M. Bohtlink, who examined the glacial phenomena of Scandinavia with great care, found there, as we have done in Scotland, many examples of striation in the direction of the valleys. But he also found on the intermediate heights the normal direction observed, sometimes at an angle of 50° to that of the valleys. This is precisely what I have found in Sutherlandshire. I have myself seen something of the glacial phenomena of Scandinavia, and fully believe that local glaciers once filled many of the valleys of that country. The moraines of the celebrated Gulbrandsdalen, at Mosshuus and Laurgard, which I have described elsewhere, are not to be mistaken. There are, moreover, in Lapland and Finland clear proofs of glaciers having run out to north-westward and north-eastward. But to rest content with the idea that the direction of *all* such action can be traced back to the great plateaux—which is the case of English geologists at this day—is to stand in a position which I am certain cannot be maintained. Take the following facts of my own observation, as only a selection of reasons which might be adduced for that conclusion.

In the very midst of the Scandinavian plateau, on the summit of 4000 feet elevation at Jerkind, and in the immediate neighbourhood of Sneehatte, the southern slope is abraded and polished almost to the top, with striæ between north-east and south-west—a line totally irrespective of all the great mountains of the district, such as Sneehatte, which it sweeps laterally. There is, in fact, no higher ground from which the required agent could descend to this spot: the effects have clearly been produced by an agent *crossing the chain.* There is, indeed, in the neighbouring valley of the Driv, an abrasion running downwards to the north, with a great lateral moraine at a considerable elevation along the mountain side; and this is the undoubted memorial of a local or valley glacier, easily traceable to the hollow grounds around Sneehatte. It is easy, however, to see that the markings at

Jerkind, being wholly unconnected with either more elevated ground in which an ordinary glacier could be formed, or with a valley in which it could be contained and directed, must have had a totally different history. Again, on the summit over which the road from Lavanger to Sundsvall passes, and the great connecting line between Norway and Sweden in that quarter, the *col* is a wide saddle-formed space, with only gentle heights on both sides, but crossed transversely by a group of low ridges. The whole of this space, composed of rocks of chlorite schist, is abraded by an agent which has been able to shear sharply through the upturned edges of the strata, leaving clear striæ to mark its course. Surprising to say, that course has not been across from west to east, as the road passes; neither has it been from north to south in the line of the little ridges; but it is athwart both of these lines of hollow, from north-west to north-east, and thus clearly has been independent of the form of the country. It is not till we see such demonstrations as these, that we can fully apprehend the weakness of the position which English geologists have been contented with for the last ten years, in believing that every thing may be accounted for by detached masses of floating ice, set in motion by currents.

It is a remarkable feature of the northern peninsula, that the descent from the great back bone of the country towards the west, constituting Norway, is by a series of comparatively short, steep, deep valleys, generally very bare, or only presenting certain alluvia in the lower and wider spaces towards the sea, while the slope towards the east, constituting Sweden, is gentle and open, with an enormous abundance of detrital accumulations spreading over all for many miles, from the flanks of the hills, where they reach to a great elevation. It was my fortune to pass across the Plateau from Norway into Sweden, and I felt myself to have been quite unprepared for the accumulations which I met with in the lee of the hills, immediately on descending from the bare striated *col* above described. The matter took the form of vast terraces, with promontories of the superior stretching into the inferior, and while the surface matter was always water-worn and water-

laid, the interior, wherever laid open for road material, shewed of precisely the same character as the stuff constituing the moraines of the Alps. Now, it would be necessary for the exclusive advocates of a drift by floating ice radiating from mountain chains, to shew how there has been such a drift from one side of that of Scandinavia, while there is so little in the opposite direction. They would need to prove that this detrital accumulation in the lee of a mountain chain, is any thing different from the familiar phenomenon of a tail of debris in the lee of a second or third rate hill, or of an isolated rock, and ought not to be set down to the same cause; namely, the chain having been involved in a flow of ice, in some form, in some circumstances, which pressed hard upon and swept bare the hither side, but, passing with comparative lightness over what lay beyond, left there some of the solid matter with which it was charged.

It is also to be remarked how little help any such mountain chain as that of Scandinavia is really calculated to give us in explaining some of the phenomena. On the shores of the Gulf of Bothnia, and in Finland, where there are vast spaces finely polished, with striation from NW.; in the country near Stockholm; in the district between Christiania and Christiansand, and around Gottenburg, where the polished surfaces are equally extensive, but where the striation has a bend towards the south-west; we are many hundreds of miles from that presumed centre of action, and the intervening space presents an infinite number of minor obstructions, all of which, however, have been swept over by the agent, whatever it was. If glaciers proceeding from the plateau be presumed, we should require to know how any such agent descending from hills only half as high as the Swiss Alps could travel over twenty times the space, in a condition, too, necessarily attenuated, through the wideness of the country over which they must have spread. If ice-floes dragging detritus over the surface are presumed, it should be shewn how any such agent could be impelled over the submarine heights and hollows of such an extent of country, everywhere pressing as hard upon the sea-bottom as if its full weight were exercised upon it under subaerial circumstances.

The general glaciation of which we see traces in Scotland, finds a still more unequivocal parallel in the northern part of the American Continent. It is well known that there are proofs all over Canada, and to a point far south in the United States, as well as around Lakes Huron and Superior, of an abrading agent for the most part from the north-west.* Mountains of 2000 feet in height bear on their sides and tops striation in that direction ; while to the north-westward, no mountains of greater elevation to serve as gathering-places for glaciers can be pointed out. Scandinavia, indeed, would be in precisely the same circumstances as North America in respect of these phenomena, if there were no such lofty chain as the Dovre-Field to variegate its surface —hence that plateau may be presumed to be quite indifferent in the case, except as a proof of the grandeur of the agent which could over-ride such elevations.

Speculations on the Causes of the More General Glaciation.

When the phenomena of ancient glacial action in the region of the Alps were first observed by Messrs Charpentier, Venetz, and Agassiz, it was thought that the abrasion of Scandinavia, which had been described some years before and attributed to floods, might be accounted for by an extension of the polar ice over that region, and its movement southwards, under the influence of a principle of dilatation, supposed to reside within the glacier itself, and believed to be dependent on the infiltration of water into chinks and its subsequent freezing. This doctrine of dilatation has been, as is well known, very generally abandoned, in consequence of the demonstrations brought by Professor James Forbes in favour of his proposition, that "a glacier is an imperfect fluid, or a viscous body, which is urged down slopes of a cer-

* Sir Charles Lyell shews that the ordinary and natural course of icebergs borne by currents is from the NE. to SW.; and in his attempt to account for the glacial markings in America by that agent alone, he observes that the general direction is the same as that of the icebergs. But I find that, in Bigsby's map of the glacial phenomena of Northern America,* the direction in by far the greater number of the markings is from NW. to SE.

* Quarterly Jour. of Geol. Soc. April 1851.

tain inclination, by the mutual pressure of its parts." In the eagerness to give up this view of a possible cause, the very fact of the glacial abrasion of Scandinavia has been also given up by many, as if the two things had been essentially connected. At least, we have for some years heard little of the abrasion either of that region or of America. Most geologists seem to be content to regard the phenomena, in the reduced or restricted form in which they contemplate them, as capable of being produced by floating icebergs which had grazed the bottom of the sea in their voyage southward, when the land in that quarter was submerged, or by these agents joined to ice-floes and masses of detritus carried along by powerful currents.

I must profess myself unable to see the force of the logic which demands that certain phenomena should be regarded as non-existent, or reduced to some fraction of their actual extent, because one theory of the mode of operation of their assumed cause has been found untenable. Be the value or fate of the Dilatation Theory what it may, it can make no change in the fact, that all over Scandinavia, below a certain elevated point, the rocky surface, wherever it has been duly protected and is now exposed, or even in some instances where it has been exposed for ages, is found to be worn or shorn down to a flowing outline, is polished, furrowed, and striated, exactly as we see that the surfaces of elevated valleys in the Alps are worn, polished, and striated by the glaciers moving in them at the present day. This fact still remains to be accounted for; and if one line of speculation on its cause shall fail, the right course, I apprehend, is to look out for another.

It is remarkable that Professor Forbes himself has been far from giving countenance to any such consequence of the refutation of the Dilatation Theory.

It is, however, far more remarkable that the prevalent theories of English geologists on this subject are all based on data for which no tangible proof has ever been, or perhaps could be, adduced. One speaks of "large islands and bergs of floating ice which came from the north, and, as they grounded on the coast and on shoals, pushed along all the

loose materials of sand and pebbles, broke off all angular and projecting points of rock, and when fragments of hard stone were frozen into their lower surfaces, scooped out grooves in the subjacent solid strata." Now, the floating and stranding of icebergs are familiar facts; but no one ever saw a sea-bottom worn or scratched by such an agent, or could prove that such an operation ever takes place, except at the utmost in a partial and casual manner. It is in the main a conjecture. Another was not long ago satisfied that "waves of translation," breaking away from centres where a sudden upheaval of the land had taken place, were sufficient to account for the phenomena, but appears to be now of opinion that glaciers, floating ice, and currents, have all been concerned in producing the effects, though still without addressing himself to, or admitting, the fact of the parallelism of striation over a large surface, which no such agents could have produced. Sir Roderick Murchison surmised that "the ice-floes and their detritus might be set in motion by the elevation of the Scandinavian continent, and the consequent breaking-up of the great glaciers on the northern shores of a sea which then covered all the flat regions of Russia." But this is an operation which has never been seen in nature, and, even though it were to take place, we hold that the ice and detritus, borne along in a wave of the sea, are still incompetent to produce the various effects of abrasion, polishing, and striation, which are to be accounted for. Besides, Sir Roderick would need to shew—what he has not attempted—that the British islands and Northern America had a similar northern mountain chain to send forth the ice-floes and detritus required in their cases. We have always been led to understand that it was a rule of scientific geology to refer ancient phenomena to causes which we see producing similar effects at the present day; but here the rule seems to be set aside in favour of a cause which has no known effects whatever.

It may be asked, can we seriously attach the least value to any theory which either ignores the great and palpable facts, or leaves them totally unaccounted for? Yet this is the character of the theories here referred to. I shall proceed to

state a few only of the facts which are thus overlooked and slighted.

The first is the extent and direction of the operation of the agent in the North of Europe. In the central parts of Sweden, and the southern parts of Norway, there is but one system of mammillated rocks and of striation—this being from NNE. and NE. :—it involves hills of several hundred feet in height, and passes across and athwart valleys, with an absolute indifference to such irregularities. Now, no free sea could produce a uniformity of movement over so wide a space, or with such indifference to forms of the surface ; and, even if the abrupt elevation of the Scandinavian chain demanded by Sir Roderick Murchison were granted, the ice and detritus thrown off by that operation could never have so soon turned off in a different direction—first sweeping to the east and then returning towards the west.

In the second place, these theories altogether overlook certain peculiar minute features of the abraded surface, which are to be accounted for as well as the general fact of an abrasion having taken place. I would instance the perfect polishing and striation of the under faces of overhanging rocks, and of the sides of certain deep narrow channels—six feet deep sometimes, and little more than one foot wide. I may point still more particularly to a class of objects which abound in Sweden, in connection with glacialised surfaces. These are the celebrated Jettegryder, or Reisentopfes (Giants' Pots or Tubs). In the midst of a glacialised surface, perhaps on the side of a mountain, perhaps on the *col* or summit of a pass through a chain of mountains, we see a circular pit of three, six, ten, or more feet in depth, and three, six, or even eight feet in diameter, with sides and bottom worn quite as smooth as the parts of the surface near by. There is an evident connection between the pit and the neighbouring smoothings in respect of cause. Generally, we find a sort of channel running up to and into the pit, forming an indentation in its lip ; and in one instance at least, I observed that a moulding descended obliquely from this entrance down to the bottom, while striæ followed the same line, the whole sides indeed being marked by curious scoopings, and interme-

diate ridgings and other evident marks of a spirality, as well as inequality of pressure, in the direction of the excavating agent. At the bottom, rounded pebbles of the size of a playing bowl are sometimes found, objects that have clearly been concerned in the hollowing process. When an English geologist hears generally of circular pits in Scandinavia, he at once thinks of aqueous action; for limestone cliffs down which water descends in a cascade, are often found so hollowed. The presence of the pebbles at the bottom confirms him in the assimilation. But were he to inspect a real Giant's Pot, he would speedily see that it never could have been associated with a waterfall, and that it has strong characteristic peculiarities altogether apart from such honeycombing of cliffs as we find at cascades. Even in the character of the skin or surface of the rock, there is a difference. In short, it is evident that these pots have been fashioned by some plastic substance which has wound round the interior, come out again, and passed on,—a substance, however, so far mixed up or associated with water, as to allow of the loose stones generally to keep at or near the bottom, or at least within the pit. Such a plastic substance, with water continually permeating its body, is the ice of glaciers. It would be difficult, I apprehend, to shew that any floating or water-impelled ice could, in its sluggish rigid movement over a sea-bottom, send down a tongue to lick and scoop out so peculiar a hollow in the subjacent rock. Still more difficult would it be for those who regard the whole of the ancient glacial phenomena as *submarine*, to shew how cascades took place at the bottom of a sea! If the theory of these gentlemen thus puts on so burlesque an aspect, I must be permitted to say, the blame is their own, for all of these peculiar phenomena have been recognised and described for many years, and yet have been passed over by them as if they did not exist.

The great defect of the ice-floe theory is, after all, the weakness of the force which it implies. If we look the phenomena to be accounted for fully in the face, we shall see that a heavy forcible pressure, by a dense yet plastic substance, has been exercised—one which could grind and mould the surface of a large tract of country, variegated by consi-

derable hills, by one movement. This could never be done by ice partially floating, or merely impelled by ordinary currents. While those who argue for the abrading powers of icebergs, can scarcely adduce a single example of that agency in nature, I can adduce negative facts of no small force against such an agency. At the falls of the copious river Glommen, in Norway, just above the cascade, the rock is seen striated under the water, *obliquely to the course of the river*. Now, this river must have upbreaks of ice every spring, filling its channel at this place with a tolerable representation of the ice-floes in question; yet no striæ are seen in that direction, and thousands of winters have failed to obliterate the original glacial markings in any perceptible degree. Many rivers of our own country have driftings of broken ice impelled down their channels with immense force at the end of every great frost; yet their rocky channels present irregularities which give them a totally different appearance from the abraded and striated surfaces. I was first impressed with this objection to the ice-floe theory on observing some rugged, or only slightly blunted points of rock starting up in the bed of the Tweed, near Peebles, where in my early days I have witnessed magnificent examples of the rush of river-ice so well described in Thomson's "Winter." This ice is, as is generally known, often impeded by grounding, and sometimes is carried gratingly over the channel of the river exactly in the manner of the ice-floes of the ocean; and, though the phenomenon is on a comparatively small scale, some memorials of abrasion might be expected, if ice carried by water were really capable of leaving any beyond the most trifling.

As an example of what may be called inadequate theories of the polished and striated surfaces, reference may be made to one lately started in Ireland, where, as is well known, such phenomena are fully as conspicuous as in Scotland. Mr Robert Mallet appears to be the real author of this theory, though Colonel Portlock claims to have suggested something similar about the same time. The main proposition is, that a detrital covering of the land, raised along with it at the time of elevation, slipped down its face into the sea, and even

over surfaces beneath the sea level, thus producing upon the subjacent rock those phenomena of rounding, furrowing, and scratching, which have been attributed to the action of ice. Such a process, Mr Mallet conceives, may be going on beneath the sea, even at the present day. The only remark I feel called upon to make regarding this theory is, that, while few would deny that a mud-slide, land-slip, or other slipping of detrital matter, is competent, when it takes place, to abrade and scratch the subjacent faces of rock, the phenomena really to be accounted for—the extensive denudations, the abrasion of mountains and valleys in directions irrespective of the inclination of the ground, and the deposit of detrital accumulations over enormous surfaces with no general slope at all (as the valley between the Friths of Clyde and Forth)—are wholly beyond the imaginable scope of such an operation.

While thus sensible of how far any existing theory is from accounting for the whole phenomena, I am by no means possessed of any theory of my own, which I think fit to be immediately accepted and maintained, without future change or modification. I can only say that it seems to me unavoidable, that we suppose a mass of ice to have spread out, from the north generally to the south, ice viscous and moveable like that of subaërial glaciers, and like them sufficiently compact to possess great abrading force; and water has been concerned in connection with this ice, as evidenced by the character of the connected deposit of boulder clay; but as to the formation and movement of this supposed northern envelope, we are not yet in a position to speak positively. All we can do is to enter upon a few speculations in connection with these questions.

What will most likely be felt as the great difficulty, is the difference between the valley containing a modern glacier, attended as it is by a mean inclination of three, four, or more degrees, and a wide extent of country without retaining walls, and with only certain inequalities throughout its surface. We see, it will be said, how gravitation will produce a flow in the one case, but not in the other. The difficulty, after all, will be found to rest chiefly on this supposed necessity for the force

of gravitation to pull a glacier along in its bed; for it so happens that the main effect of Professor Forbes's investigation, has been to impress such a notion, while the actual terms of his proposition are forgotten or overlooked. These were, that a glacier is "urged down a slope of a certain inclination, by the *mutual pressure of its parts*." As far as I can understand the views of our learned associate, there is a hydrostatical pressure from a column of the same material acting on a superior level, and thus pushing along what is at the lower level. Mr Forbes says, "Pure fluid pressure, or what is commonly called hydrostatical pressure, depends not at all for its energy upon the *slope* of the fluid, but merely upon the difference of *level* of the two connected parts or ends of the mass under consideration." It appears that the less fluid the body, the less is this the case, from the resistance which the viscosity presents; but, at the same time, the greater the viscosity, the more will the retardation due to friction be distributed throughout the mass; so that the sliding of the bottom of the fluid over its bed, will be the more facilitated. The glacier, of course, being a highly viscous body, will be comparatively slow to yield to the hydrostatical pressure of the more elevated parts; but it will, and does yield in a certain reduced degree, and its comparative viscosity ensures that its base shall not be left greatly behind its middle and superficial parts—that it must, in short, slide *bodily*, and so graze the bed or surface over which it moves.

The question occurs, over how small an inclination will a mass constituted in the manner of a glacier slide? We see glaciers in the Alps, moving at the rate of above two hundred yards in a year, over a bed with walls and impeding projections, which has a mean slope of 5°. Will it move at all over a very much smaller inclination? We have an answer on this point from Professor Forbes:—"Large and deep rivers," says he, "flow along a much smaller inclination than small and shallow ones. . . . The most certain analogy leads us to the same conclusion in the case of glaciers. We cannot, therefore, admit it to be any sufficient argument against the extension of ancient glaciers to the Jura, for example, that they have moved with a superficial slope of one

degree, or in some parts even of a half or quarter that amount, whilst in existing glaciers the slope is seldom or never under 3°. The declivity requisite to insure a given velocity, bears a simple reference to the dimensions of a stream. A stream of twice the length, breadth, and depth of another, will flow on a declivity half as great, and one of ten times the dimension upon one-tenth of the slope."

If this be the simple principle concerned where there is a declivity, it is easy to see that a very small declination from the north to the south of Scandinavia, or of Northern America, would suffice to allow of a movement for the supposed general glaciers of those regions, seeing that there is tolerably clear evidence of these glaciers having been on a scale of volume immensely exceeding the glaciers of the Alps. Judging from the abrasions they have left on hills, and the height to which their detritus extends, they must have been several thousands of feet in depth.

But it appears as if it were not necessary that there should have been any sensible inclination of the general surface over which these supposed glaciers extended, if it be true, on the hydrostatical principle announced by Professor Forbes, that they would move under the influence of sufficient accumulations in any quarter, in the directions in which they found least resistance. Supposing such accumulations on circumpolar grounds, there would be a spreading movement to the south, liable to be affected to some extent by accidental impediments; in short, very much such a movement as the glacial phenomena of northern countries lead us to expect. To such an extension of the operations we now see, it is only further necessary that the meteorological conditions should have been such as to maintain the plasticity of the material; and this is a point on which we have assuredly no data that would at once and decisively negative the demands of the present theory.

The nearest approach that we are acquainted with in nature, to the case here supposed, appears to be that afforded by the phenomena of the land discovered by Sir James Ross in the 79th degree of south latitude. "The vessels were here stopped by a barrier of ice from 100 to 180 feet in

height, and extending 300 miles from east to west. Beyond these ice-cliffs a chain of lofty mountains was discovered, rising from ten to twelve thousand feet in height, and covered with glaciers and ice-fields. From the sea-face of the frozen barrier reached by the vessels, huge masses were constantly breaking off, and floating northward, bearing with them fragments of rocks which had been derived from the mountains." Such is the description given. It appears that here was a tract of ice 300 miles in extent, moving outwards from land, with detritus. It must have been viscous ice, or it would have had no motion; although, at its extremities, where the fragments were breaking off, a more solid character may have been assumed. It seems to realise, on a very considerable scale, the extensive glacier-sheet demanded by the phenomena of abrasion in the opposite portion of the globe.

We have, from motives of convenience, withheld till now all but the most partial consideration of those superficial deposits which are so palpably connected with the present subject. It is obviously necessary that these should be explained in harmony with any theory of the abraded surfaces which we can expect to be received.

In Sweden, as far as my observations extended, the kind of matter usually found lying immediately upon the smoothed rocks, and in the lee of eminences, is a confused mixture of blocks of all sizes, imbedded in coarse sand and clay, with no sorting observable in any part. Very generally this mass is of a straw colour, and so exactly does it resemble the detritus found at the sides and skirts of existing glaciers, that I have been led to adopt for it the term *Moraine Matter*. It seems to be the direct and invariable effect of glaciation taking place on inclined ground under the atmosphere. This matter is, everywhere in Scandinavia, covered with beds of sorted gravel, sand, and clay, betokening a subsequent watery action, as if the masses had been submerged, and a partial change effected on and about them by that means. In many places, this alluvial or aqueous formation is presented in ridges called *ösar*, which traverse the country in determinate directions, often extending for many miles. Shells are found in the aqueous deposit, but never, as far as I have

heard, in the subjacent moraine matter. Besides these formations, there is the still more superficial one of erratic blocks, which, affiliated to Sweden and Finland, extend southward into Denmark, Germany, and Russia, at least as far as the 50th parallel. These rocks are less worn than those of the lowest deposit, and yet are carried much farther. It is likewise of importance to observe, that they have been carried over the intervening line of the Valdai Hills, which rise from 800 to 1100 feet above the sea.

The superficial deposits of Northern America bear a general resemblance, in their important features, to those of Northern Europe.

In our island, the superficial deposits constitute a series, of which no fewer than six, if not seven, members have been described by some observers, though it is seldom that so many are present at one place.

One noted deposit very generally found resting on the rocks in Scotland, is the *Boulder Clay* (No. 1.) It consists of a remarkably compact menstruum of clay, blue, black, or of some lighter colour, totally impervious to water, and only assailable by the pickaxe; which breaks with irregular fracture; has no trace of lamination; and through which are interspersed blocks of all sizes, which have travelled from places within forty or fifty miles, usually rounded, often worn into a sort of sole on one side, presenting striæ or scratches. This deposit is found, in Mid-Lothian, nearly 1000 feet above the sea, and, in some places, is stated to be not less than 160 feet deep; shewing an amount and extent of operation for the abrading agent in which it took its rise, perfectly enormous. A railway cutting made in this deposit on Middleton Muir, in a situation not less than 700 feet above the sea, was about fifty feet thick.

In the valleys of the Forth and Clyde, where the boulder clay is very largely developed, the included blocks are all from the westward, the direction of the agent which has produced the furrowing and striation of the district. At several places, strata cropping out westward under the clay, have been found bending off back to the east, with the clay insinuated in the gap, clearly proving at once an east-going force, and a partially liquid state of the clay at the time of its deposition.

At Linksfield, near Elgin, there is a horizontal chink between a limestone bed and the superior oolite strata, from three to four feet deep, and this is filled for several hundred yards inward from its mouth with boulder clay, which has found an entrance from the *north-west*, and scratched the planes above and below, between which it has been insinuated.

In a few isolated situations, a bed of sand has been found between the boulder clay and the subjacent rocks, and Mr Milne Home mentions an instance in which some of the materials of this sand could be traced to an *easterly* situation.

The generally azoic character of the boulder clay is one of its most remarkable features. Besides a fragment of an elephant's tusk, represented as having been found in it by some workmen in 1820 at Cliftonhall, in Mid-Lothian, Mr Milne Home, who gave great attention to the formation and its history, had never, in 1838, heard of a single instance of organic matter found in connection with it. More recently, shells of the existing epoch have been found by Mr John Cleghorn, liberally scattered through its depths in Caithness; but they are all water-worn, and can, therefore, be only classed with the inorganic materials. Mr Smith of Jordanhill discovered shells in the like state in the boulder clay; and Mr Carrick Moore lately announced an entire valve of *Astarte compressa*, as being found by him in the same formation in Wigtonshire,—a solitary exception to the rule.

I have only within the last few days been made acquainted by Mr Hugh Miller, with a curious and, as yet, unrecorded feature of this mysterious deposit, as it occurs in our own neighbourhood. It is well known that between Leith and Portobello, and between Portobello and Fisherrow, there is a cliff of the boulder clay on which the sea is making perpetual aggressions. The beach in these places is partly composed of a rough though levelled platform of boulder clay, with some huge blocks resting on it here and there that have been washed out of the superior mass, now carried away. At several places the eye can detect a narrow train of blocks crossing the line of beach, somewhat like a quay or mole, but not more than a foot above the general level, and not at a

right angle to the line of the coast. All of these blocks have flat sides uppermost, and all of these flat sides are striated in one direction,—namely, in that of the line of blocks. There are also some appearances of a hollow on the surfaces of these curious *pavements*, as Mr Miller calls them, as if some enormous wheel had run along the surface in that direction, and left in it a slight track. What is of the highest importance, the line of the blocks, and that of the striation, are from about WSW., both at Seafield and at Magdalen Bridge, (examples three miles apart,) this being the direction of the striation upon the fast rock throughout the whole of our district, so that the presumption for a community of cause becomes very strong. There is, in short, a surface of the boulder clay, deep down in the entire bed, which, to appearance, has been in precisely the same circumstances as the fast rock-surface below had previously been. It has had in its turn to sustain the weight and abrading force of the glacial agent, in whatever form it was applied; and the additional deposit of the boulder clay left over this surface, may be presumed to have been formed by the agent on that occasion.

Professor Fleming, to whose superior experience I am much beholden in this part of my subject, assures me that the deposit most generally found in our district over the boulder clay is a fine laminated clay, or silt, evidently derived from the preceding formation, in which it sometimes fills up considerable irregularities. This is the clay generally wrought for bricks and tiles throughout Scotland, so that we may be said to be indebted remotely to these glacial phenomena, both for the houses which shelter us, and the increase of food required by the exigencies of a large population.

The laminated clay is succeeded by, or perhaps we ought rather to say, associated with, an abundant formation of fine sand, disposed in beds, and intercalated with gravel. Very often there are interlacings of the sand and the clay, or curious nests of sand within the clay, shewing rapid and abrupt alternations of conditions in the sea, in which the whole had been formed. In this compound formation, as I venture to call it (No. 2), shells are found—*Mya truncata*, *Saxicava sulcata*, *Tellina calcarea*, *Astarte borealis*, *Cyprina islandica*,

Mytilus umbilicatus, *Littorina littorea*, *Buccinum undatum*, *Natica clausa*, *Balanus sulcatus*, suggesting an arctic character in the sea of the period. Remains of large quadrupeds have also been found in this set of deposits. In the deep beds wrought for bricks at Portobello, large trees are reported as having been found by the workmen, and thought by them to be of oak; as also, bones "as thick as a man's thigh." They are likewise understood to have found hazel nuts lying on the surface of the deposit.

This evidently aqueous formation of a tranquil era, during which there had been dry land inhabited by the elephant, rhinoceros, stag, and other large mammalia, is succeeded by what Mr Milne Home calls the *coarse gravel* or *stony clay*, but what is more generally recognised in Scotland as the *till*, being the subsoil of many of our fields (No. 3). This formation may be described as a layer of rough stones, embedded in a light-coloured clay, not so thick as the boulder clay generally is, while the included blocks are also of smaller size. It has no laminæ, no organic remains, and has all the appearance of having been the product of violent agencies. It appears to be often confounded with the boulder clay, and thus has given rise to some serious mistakes regarding the arrangement of the superficial deposits. It is often, however, placed immediately over the surface of the rocks.

Over this again comes a new series of sand-beds (No. 4), containing thin layers of gravel, and fragments of coal,—a very wide-spread formation in our immediate neighbourhood, and throughout Scotland generally. Mr Milne Home found it at Blackshiels, 700 feet above the sea, and it probably exists at greater elevations. This very careful observer had not heard of any shells being ever found in it.

The same gentleman has described a raised beach which extends along the Firth of Forth, (No. 5,) rising from fifteen feet in the east, to about thirty in the west, above the level of the sea, in which he found beds of shells of existing species; and this appears, from his description, to be an intercalated formation, though probably represented by some of the shell-bearing beds found by Mr Smith of Jordanhill, and Mr John Craig, in the basin of the Clyde. The bed is

one of exceeding value in the present disquisition, as it indicates that at this particular period, the relative level of sea and land, in our district at least, had been reduced from the high point denoted in the preceding formation, down to one not more than thirty feet above the present. It was a period, in short, of extensive dry land. As might be expected, the rivers had in this period worn out hollows in the solid structure of the country; amongst other such cuttings was that of the Water of Leith at the Dean, in our own neighbourhood. So, at least, Mr Milne Home infers, and with good reason, from finding on the sides of that hollow, a bed of the next formation.

This was a third boulder bed (No. 6), a drift of coarse gravel, connected with the well-known erratics, which, however, are very generally superficial. This formation must be regarded as, in our district, consequent upon a deep and abrupt re-immersion, for it spreads up to elevations even higher than the boulder clay. The long ridges of gravel, called in Scotland *kames*, and identical in character with the *ösar* of Sweden, and *eskers* of Ireland, belong to this formation; and the various ancient beaches which can be traced from several hundred feet above the sea, down to its present level, may be considered as the memorials of stages or pauses in the subsequent and final emergence of the land. The vegetable soil completes the entire series, being the product of historic times.

In the basin of the Clyde, there are some differences in the suite of deposits, though the general harmony is sufficiently clear. Mr John Craig describes the following series as existing at Glasgow:—

4. { Sand under Trongate.
   Laminated clays with recent marine shells; newer portion containing only fresh-water shells, as *physa*.
3. Boulder till. (What are below appear at Bell's Park.)
2. Sand.
1. Lower boulder till.

The boulder till (No. 1), at Bell's Park, contains an abundance of worn and striated boulders, and the subjacent sandstone exposed in making the Caledonian Railway Station

presented, within the last two years, a piece of polished and scratched surface, which, however, has since been quarried. The blocks are of granite, porphyritic traps, mica-slate, greywacke, red sandstone conglomerate, and quartzose rock, all of which are found in the Highlands many miles to the north-west; besides some less worn coal, sandstone, and carboniferous limestone, from the immediate neighbourhood of Glasgow.

In another situation, between Greenock and Port-Glasgow, Mr Smith of Jordanhill found the following deposits, which, as in the above case, we venture to assign to their relative places by numbers:*—

Vegetable soil.

3. Coarse gravel, two feet.
2. { Sand, ten feet.
   A series of thin beds of sand, gravel, and clay, full of sea-shells; (33 species found at two visits).
1. Diluvium.

The same diligent observer has described a deposit of shells found at Airdrie, in digging a coal shaft, at a spot 524 feet above the sea:†—

3. Upper till.
2. Stratified clay, in connection with which the shells were found.
1. Lower till.

It must be admitted that there is some uncertainty in assigning these relations, the imperfection of the description making certainty for the present impossible.

The superficial formations of England have been described by various local observers, but with such a want of concert and relation, that it is extremely difficult to reduce them to any conformity even amongst themselves, much more to bring them into harmony with those of Scotland.

The region of Siluria—the south-east-looking slope of the hills of North Wales, and adjacent districts of Herefordshire, Worcestershire, and Salop—is described by Sir Roderick Murchison, as presenting a local drift—that is, a drift com-

* Memoirs of Wernerian Soc., viii. † Quar. Jour. Geol. Soc., vi. 386.

posed of materials derived either from mountains forming the north-western limits of the country, or from rocks of the very district where the materials are found. "Not only the valleys, but various elevated *combs* and basin-shaped cavities, as well as the slopes and escarpments of hills, are strewed sometimes with boulders, coarse gravel, and clay, at others with finely comminuted materials. . . . In passing to the south-east, the coarse boulders disappear, and the gravel becomes more and more finely comminuted, shewing that the direction of the drift has been from the north-west." Connected with this drift are proofs of extensive denudation, such as the conical hills called the Pyons, lying five miles from the principal masses with which they were once connected, the valley of the Severn lying between,—and the lofty peak Pen-cerrig-calch, an outlier of the South Wales coal-field divided from its principal by an intervening valley twelve or fifteen hundred feet deep.

Sir Roderick further describes a central tract of Western England, composed of large portions of Lancashire, Cheshire, Shropshire, Staffordshire, Worcestershire, and Gloucestershire, where the local drift is overlaid by a drift which has come from the north, bearing fragments of granite and other rocks, of which the original position is comparatively distant, and in which are found deposits of shells of existing species. He conceives that Siluria had been dry land at the time when a northern sea-current deposited this higher and later drift.

The same northern drift lies in large masses on the north coast of North Wales, and in elevated portions of the Snowdonian region, where shells have been found in it at 1392 and 2200 feet above the sea; but, as has been remarked, it seems to have been swept out of the Snowdonian valleys by comparatively modern glaciers.

Professor Phillips describes the drift in a part of England more to the northward. Masses of the porphyritic granite of Shap Fell, and portions of other highly peculiar rocks belonging to the Lake country, have been carried "northward in the vale of the Eden to Carlisle, southward by the Lune

and the Kent to the barren tract between Bolland Forest and the bay of Morecambe, and from the vicinity of Lancaster they are traced at intervals through the comparatively low country of Preston and Manchester, lying between the sea and the Yorkshire and Derbyshire hills, to the valley of the Trent, the plains of Cheshire and Staffordshire, and the vale of the Severn, where they occur of great magnitude. It thus appears that the Pennine chain, ranging north and south, acted as a great natural dam, limiting the eastward distribution of the blocks; but at Stainmoor, directly east of Shap Fells, a comparatively low part of the chain (1400 feet above the sea), granite from Shap Fell, which is 1500 feet, as well as sienitic rocks from Barrock Fell, which is 2200 feet, and red conglomeratic masses from Kirby Stephen, only 500 feet above the sea, have been drifted over the ridge. This great boundary passed, the blocks are scattered from Stainmoor, as from a new centre, to Darlington, Redcar, Stokesley, Osmotherly, Thirsk, and the whole front of the Hambleton hills; they have gone down the whole length of the vale of York, and by the base of the chalk wolds to the Humber." To the south of the point of passage here described, the boulders of the Lake district lie up against the Pennine chain "in enormous quantity, and in the most inextricable confusion, not to be explained by anything like the action of the sea on its coasts, even during the most violent storms."

In Norfolk, the series of superficial deposits is thus set down by Sir Charles Lyell:

3. Erratics.
2. Fresh-water deposits, with beds of lignite and submarine forests.
1. Unstratified clay or till, lying on the Norwich Crag.

Mr Trimmer describes the superficial deposits of the country between Congleton and Macclesfield, as follows:

3. Upper Erratics: sand and gravel; large northern boulders.
2. Till: "a red clay containing many small fragments having a northern origin, and much detritus derived

from the neighbouring chain." Contains scratched fragments, but these supposed to be local. Fragments of shells.

1. Sand, a deep bed, with erratic detritus.

At Weymouth, according to Sir Henry de la Beche,* the rocks, inclusive of the chalk, have been subjected to great disturbance, producing enormous faults; but the surface has subsequently been exposed to "a tremendous inundation, which has swept away all the rubbish and ruins of the elevated masses, and has excavated valleys of many hundred feet in depth on the surface of the strata that remain. Outlying summits composed of residuary portions of the strata which are continuous along the escarpments on the north and east of the valley of Bredy, indicate the original continuity of these strata over large portions of that district from which they have been removed."

In the district of Chatham and Rochester, according to Mr R. Dadd,† there is the following series of deposits above the upper chalk:

4. Alluvium.
3. Diluvium: from 6 to 10 feet thick; water-worn chalk, with unworn flints. Remains of deer, elephant, rhinoceros, &c.
2. London clay.
1. Plastic clay. Shells of *ostrea*, *cyclas*, and *cerithium*.

Amidst the obscurities produced by the want of a uniform nomenclature, it is easy to see that the till, diluvium, and northern drift are all one formation, identical with the till or second boulder clay of Scotland. In the Silurian region there is a lower drift, marked, like the lower or true boulder clay of Scotland, by the comparatively local character of the detritus, and which may be presumed to be contemporary with that formation. Over the till or northern drift, again, there are other deposits of a tranquil ocean, as in Scotland. There are also, as in Scotland, about this part of the series, remains of land vegetation. Subsequently come large un-

* Geol. Proceedings, i., 220. † Ibid., i., 482.

worn northern erratics, generally occupying a superficial position. Thus the sequence of events seems the same over the island, though all are not everywhere expressed,—a result which no geologist will have any difficulty in accounting for.

It must be evident, when the whole subject of the superficial deposits is thus analysed, that the vague general view which is often taken of it by geologists, is one which can only be entertained in defiance of facts. It is placed beyond all question, that these deposits form the record, not of one epoch, when our land was under a glacial sea charged with icebergs, but of a succession of conditions in which the land sunk and rose, and sunk and rose again, and during which phenomena of very various character took place. It is not possible, in the present state of the investigation, to speak with precision of this succession of conditions and phenomena; but I may venture to point out what the facts suggest in the case, so far as we are yet acquainted with them, leaving to future inquirers to make such modifications of my provisional view of the matter as may appear necessary.

The more general glaciation which has here been described, with its attendant memorial of a detritus of striated local blocks and clay, points to a wide extension of the circumpolar ice, and a southern movement of that envelope, in the course of which the surface was abraded and the detritus produced. This icy sheet is shewn, however, not to have been everywhere in precisely the same condition as a glacier of the Alps, for there is a difference in the character of its detritus. The boulder clay indicates a comparatively fluid state of the ice, whether from passing across shallow seas, as it may have often done, or simply because the water which itself produced rested amongst its particles, instead of being drained away, as it always is, in a valley glacier. There being in the detritus of this glaciation no far transported blocks, I attribute to the severity of the attrition to which they were subjected. With this glaciation, moreover, is connected much of that denudation which has hitherto been attributed exclusively to floods.

After this glacial period, the land had been partly sub-

merged; those parts which remained above the waves were the residence of the large mammalia, while under the waters there took place deposits of plastic clay, washed off from the boulder clay, alternating with beds of sand, of which the materials were obtained from the hills.

Next succeeded a new cold period, in which the masses of the land produced glaciers descending with their subaërial detritus into the sea, as we see at this day in Spitzbergen. Borne along in determinate directions by currents, the ice-borne detritus was strewed along the sea-bottom, so as to form the *till* of Scotland, the *drift* of England, and the corresponding deposits of Northern Europe and America.

This also passed away, giving place to renewed deposits of sand and gravel under an ordinary sea.

Then was a period of larger extent of dry land,—larger, even, than what now exists. Districts now little above the level of the sea, and some a little below it, were then so far elevated as to be subjected to a comparatively severe temperature. What are now low grounds in Hampshire, bore the coniferæ and other trees now proper to the Scottish hills. Snowdonia, the Lake Country, Assynt, the Cuchullin Hills, and other districts in Scotland, were the seats of glaciers like those now existing in the Alps, by which the detritus of an earlier cold period were swept out of the valleys forming their beds.

Then came another deep submergence, attended still by great cold. Masses of ice floating away from the insulated hills, bore off large blocks in the direction of the prevalent currents, and thus the Criffel granite became strewed in Cumberland, and the Shap granite was transported to the plains of Salop and the vale of York.

The emergence consequent upon this state of things, still attended by a low temperature and a transportation of erratics, was by stages, to which must be attributed the ancient beaches now traceable over the face of the country.

Perhaps the most valuable effect of the facts here adduced is in the light which they throw upon the great, but hitherto mysterious processes of denudation and the formation of valleys. To suppose water capable of cutting out all the wide

and deep spaces which exist between the principal masses of certain formations and their outliers, has always appeared to me a violent supposition, and one with which we could not rest. When, surveying the Old Red Sandstone district of Sutherland and Ross shires, I found the enormous relics of that formation, and the vast spaces left between them, marked with the traces of an agent possessed of much higher mechanical force, I felt how much more satisfactory it would be to regard *that* as the great denudator, though certainly not to the exclusion of water, the wearing force of which is everywhere conspicuous within its own limits. To the south of Lake Wenern, in Sweden, there is a series of hills, of about 700 feet high, composed of horizontal transition strata, and the gneiss surfaces between are all polished.* This is a case perfectly parallel to that of the Ross-shire mountains, and doubtless many other instances might be found. Valleys are generally formed in the lines of ancient breaks or faults. Such is the case with the valleys of the Lake Country. But as Mr Hopkins remarks—"The inspection of a model in which heights and distances are on the same scale, must make it apparent that the actual *widths* of the valleys in question could not possibly be derived from the fractures in which we may conceive them to have originated."† It is equally evident that after certain longitudinal and descending hollows had been formed by fracture, these, becoming the seats of moving ice, would in time be widened to the extent which we now behold.

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* Bohtlink; Edin. New Phil. Jour., Oct. 1841.

† Quar. Jour. Geol. Society, iv., 86.