

clay mark the old land surface, and the layers of marine shells which have been or may yet be found in the same deposit, show some of the successive stages in the process of submergence by which that land surface became by degrees the bed of the sea. We can understand, too, how the boulder-clay, if preserved in this way during its descent, should remain so perfect over such wide tracts of the country. And we are enabled in some degree to explain why the proper marine drift is not more extensively developed, for it probably received but little augmentation during the sinking of the land. Its origin rather dates from the time when the land, freed in part from its mantle of ice, began again to rise from beneath the sea. To the evidence from which the history of this second portion of the Drift period is to be compiled, we must now turn.

II. RE-ELEVATION OF THE COUNTRY: ORIGIN OF THE STRATIFIED DRIFT.

The boulder-clay is covered with occasional deposits of sand, gravel, and stratified clay, in which marine organisms are in some places found.¹ As these strata ascend to a considerable height above the sea, it is evident that the land must have been, at least to that extent, submerged below the sea-level. I have already adduced evidence, which seems to render it probable that this depression took place during the accumulation of the boulder-clay. I am not aware that the marine deposits themselves afford any indication of having originated during the sinking of the land, nor indeed is such an indication to be expected. According to the theory which maintains, that while the country was going down beneath the sea, it was covered

¹ I have been greatly at a loss for an intelligible, comprehensive term to express the sands, gravels, and clays which overlie the till. "Stratified Drift," though in most cases applicable, will not always do, for there are instances where this Drift is not stratified. "Marine Drift" is likewise objectionable, for the boulder-clay is in part marine, and moreover, it is by no means certain, that some of the sand and gravel heaps which are classed together in this Drift, have not been produced by freshets on the land. If the word "Drift" had not already been unfortunately used as a general term for the whole of the glacial deposits, it would have served well to denote the upper water-formed beds, "till" or "boulder-clay" being reserved for the lower or ice-formed mass.

over with a wide sheet of ice, the amount of marine denudation would largely depend upon the extent to which the coasts were free of ice, so as to be exposed to the action of the waves. If the cold was so severe as to envelop the island in ice, it must have told not less powerfully upon the sea. Not only would a crust of ice form upon the surface of the salt water, but there would also, in all likelihood, be a thick "ice-foot" along the margin of the land. The waves of the summer storms would thus find comparatively little scope for their ordinary work of demolition, for, save along exposed headlands, they would probably break upon ledges of ice, sometimes upon the protruded mass of a sea-going glacier, sometimes upon the thawing terraces of last year's ice-belt. The chief amount of destruction would be done by the frosts loosening masses of rock, and piling them upon the frozen shelf below. When this rubbish-charged belt was broken up, and carried out to sea, it would drop its burden to the bottom. But this would not be ordinary marine denudation, and the deposits so formed would bear but little resemblance to the great majority of those which constitute what is known as the stratified or marine Drift. It seems to me, that on the whole, the amount of sand, gravel, and stratified clay accumulated by breaker-action during the submergence of the land would not be very great. The boulder-clay was being carried down, platform after platform, beneath the sea-level, and the deposits which might be thrown upon the submerged land would probably consist in large measure of the confused contents of the ice-belt or of drifting bergs, with sometimes sediment of a more ordinary kind derived by the sea, either from the shore rocks, or from exposed parts of the till.

It is on these grounds that I would assign the vast masses of stratified Drift, now to be described, rather to the time of the rising than of the sinking of the land. Whether or not their materials arose in part during the submergence, they would be re-arranged during the re-elevation, and hence, as we see them now, they tell only of an upward movement. When the country went down, it was shielded by a formidable barrier of ice from the constant assaults of the ocean; when it came up again, its protecting bulwark was gone, and its loose covering of rubbish and boulders fell an easy prey to the waves.

The submergence of a large tract of land¹ would tend to ameliorate the climate. Whether this was the main agency concerned, or whether it only coincided with some vast cosmical change affecting the whole planet, and of which as yet we know nothing, is comparatively unimportant in the present inquiry. In whatever way the change was brought about, there can be little doubt, that when the land began once more to rise, the temperature had likewise risen. The ice, in place of thickly covering the whole country, was confined to the upland corries and glens, down which, in the form of local glaciers, it may here and there have reached the sea. And the waves, instead of beating wildly against a cliff of ice, which drove them back from their natural limits, rolled in upon the hummocks of earth and stones which the ice had left behind it, sweeping away mud, sand, and gravel, and spreading them out in wide sheets over the sea-bed. Yet the winters seem to have been still severe enough for the formation of coast-ice; icebergs, too, probably floated off into the main, while on the land, glaciers filled up many of the deeper and higher valleys; and as the ice and snow which covered the country melted away, sometimes perhaps suddenly, violent floods may have been caused, whereby the detritus was swept out of the glens, and spread out in irregular heaps over the lower grounds. It is the results of all those agencies acting, when the land, though subject perhaps to oscillations of level, was still on the whole ascending, that we have now to consider in the accumulations of Stratified Drift.

Stratified Drift: Difficulty of arranging its members chronologically.—No one who has not made the attempt in the field can be fully aware how extremely difficult it is to ascertain the true order of succession among the members of this part of the Drift series. The general sequence of events may perhaps be understood, but when we come to compare sand-bed with sand-bed, and clay with clay, from different parts of the country, we have really no reliable guide to their relative geological antiquity, or even to the circumstances of their origin. In the case of post-tertiary shore accumulations, it may be assumed as a

¹ The depression seems to have been general over the north of Europe, though probably varying greatly in extent in different regions.

rule that the higher a deposit lies above the present sea-level, the more ancient must be its origin, since in the ascent of a rising land the coast-line of any particular period is constantly receding farther and farther from the sea-margin. Hence, in other words, the older the shore-line the higher will it be found to stand above the sea. Such truly littoral deposits as follow one contour-line round the country may, perhaps, be regarded as in a geological sense contemporaneous, though in the absence of shells it is often impossible to decide whether a series of strata is of littoral origin or not. But it by no means follows either that all superficial marine deposits which lie on the same level are coeval, or that some which are found on a lower platform may not be of the same age with others which occupy a higher site. We know that at present the sand and shingle thrown up daily along the beach are strictly contemporaneous with beds of fine mud and silt that are gathering in stiller water out at sea. Hence a gravel bank on some lonely hill-top far away among the moors and mosses of the inland districts, may have been formed at the same time as beds of fine clay along the sea margin, whereon are built the villages and sea-ports of a busy human population.

The task of collating and arranging the stratified Drift becomes still more dispiriting when we reflect that the ascent of the land would constantly bring up to the tidal zone accumulations that had previously been formed at some distance below the sea-level. Hence there could scarcely fail to be a mingling of deposits which had originated at various depths from the shore-line down to deep water. Further, the action of the waves upon a bank of boulder-clay might reveal some of those little patches of shell-bearing clay which I have described as occasionally occurring in that deposit. Such fine clay-beds, if they escaped destruction, might be covered over with shore detritus in such a way that it would be hardly possible even to suspect that the shell-bed belonged to the boulder-clay and not to the true stratified Drift; to the sinking rather than to the rising of the land. Nor is this all. Though during the growth of the stratified Drift, the country was probably on the whole ascending, there seems no unlikelihood in the supposition that this upward progress was interrupted by long pauses, and even

by occasional movements of a retrograde character. Such interchanges would, of course, give the waves still further opportunities for remodelling the previously-formed parts of the Drift, and thus commingling the products of different agents and different periods.

But it is highly probable that the sea has not been the only agent concerned in the production of the loose detritus which covers the face of the country. Part of the sand and gravel mounds may actually indicate the former passage of violent land-floods caused by a rapid melting of the general envelope of ice and snow.

I do not wholly despair that the sands, gravels, and clays of each district will yet be brought into close chronological comparison with those of the rest of the country. But from this consummation Scottish geology is still very far removed. In the meantime more cannot be attempted in the present summary than a general sketch of the nature and position of the stratified Drift. I shall endeavour, however, to preserve so far an approach to the true order of succession, by describing first the deposits which occur in the higher districts, and which, since they have been longest above water, may be most ancient in origin. One or two preliminary remarks may be offered on the relations of the boulder-clay and the stratified Drift.

Its relations to the Boulder-clay.—Where the boulder-clay has been wholly washed off a hill-side, we may often trace its former existence there by the occasional striated stones which occur among the loose soil and angular rubbish resulting from the decomposition of the underlying rock. I have observed this fact again and again in the uplands of Peebles and Selkirk. We may thus trace an insensible gradation from good stiff boulder-clay to a loose surface-wash of detritus. Doubtless much of this denudation may be due to the effect of rains, runnels, and larger streams of fresh water. But such agents are far from sufficient to account for the whole of the denudation of the boulder-clay, and the heaps of water-rolled gravel and sand with which it is covered.

So far as my observation guides me, there is a considerably larger area of the country (at least of that part between the

Grampians and the Solway), where the boulder-clay comes up bare to the surface soil, than where it is overlaid with stratified beds. Sometimes it is covered with a re-assorted part of its own mass, and in such cases the two deposits may be seen to shade into each other. But there is usually a sharp line of demarcation between the till and any other bed which overlies it. Often, indeed, the surface of the till is hummocky and irregular, and the sand, gravel, and clay lying on it have been deposited in and over the hollows.

If, passing from such lesser features, we view the relations of these two portions of the Drift over the breadth of the island, we perceive, on reflection, that there is in reality an unconformity between them. The till, as we have seen, clothes the surface of the land from a height of 1700 feet or more down to below the sea-level. It forms a great mantle, sadly worn and ragged indeed, but which, in the parts that remain, accommodates itself to the major undulations and the general declivity of the ground. Now the marine Drift has been deposited more or less horizontally on successive platforms cut out of the till. Instead, therefore, of sloping down to the sea with the descent of the ground, the sands, gravels, and clays lie nearly level upon each other, rising stratum over stratum from underneath the present sea-margin away up to the hill-tops. The beds may thus, for the moment, be regarded as forming horizontal bands, which conform, in a general way, to the configuration of the country. It is evident that along the outer edge of these bands the ends of the strata are truncated by the slope of the ground, and that their inner or landward edge abuts either upon rock or against the mantle of boulder-clay. One of the best examples of this relation which I have seen is on the north shore of the Kyles of Bute, where the stratified clays and sands end off against a slope of boulder-clay. But the same feature may be traced all over the country, even where there are no sections to show diagrammatically the relative position of the various deposits. Here accordingly there is again good evidence that this stratified Drift can have had no immediate connexion with the till.

Mainly derived from waste of Boulder-clay.—That these stratified deposits of clay, sand, and gravel have been in great

measure derived from the waste of the old till or debris of the land-ice, is apparent if we compare their pebbles and boulders with those of the latter. The same conclusion is borne out by the fragmentary character of the till, and by the common replacement of this deposit by stratified beds in places where there can be little doubt the till once existed. But the stratified Drift was also in part produced by the action of the waves upon exposed rocky shores, by the sedimentary discharge of rivers or of land floods, and by the detritus carried out to sea by masses of ice. Perhaps, too, there may have been some other agency or combination of agents not yet satisfactorily understood.

Its sporadic Character.—One of the most obvious features of this part of the Drift series, is the local and sporadic character of the beds. It is only in the lower parts of the country, as along the margin of the Firth of Clyde, and in the east of Aberdeenshire, that we meet with persistent beds of clay. In the interior we encounter accumulations, chiefly of gravel and sand, with patches of stratified clay, sometimes gathered together in great masses, and then absent for long intervals. Unlike the old till, therefore, the stratified Drift is far from being distributed with any degree of uniformity over the country. Patches of it in the form of sand mounds, banks of gravel, and sheets of fine clay, resting sometimes on till, sometimes on solid rock, may be seen dotting the country for miles without uniting into one continuous deposit. These are not mere outliers isolated by denudation, for in not a few cases, the stratification of the mounds conforms to their external surface in such a way as to show, that they can have suffered but little from the wasting influences of nature, and that they remain now very much in the same state in which they were left by the sea.

The stratified Drift sinks beneath the sea-level, and ascends for at least 1500 feet above it.¹ It maintains no very definite

¹ In the Ben Muickdhuil range, Mr. Jamieson (*Brit. Assoc. Rep.* 1859, Sect. p. 114), has traced beds of drift having all the aspect of a marine deposit up to elevations exceeding 2000 feet. This drift, as was noticed by Sir Charles Lyell in Forfarshire (*Proc. Geol. Soc.* vol. iii.), is more gravelly in texture than that of lower districts; it also contains fewer, sometimes none, of the striated stones. In the uplands of the southern counties I have never seen stratified drift more than 1500 feet above the sea, and at this height but rarely.

relation to the form of the ground on which it rests. Like the boulder-clay, it is on the whole most abundant in the main valleys, but occurs also on the sides and summits of the hills. It spreads out over a wide area in the basin of the Firth of Clyde. There, however, and in some other maritime tracts, it presents features which are not seen, or at least only partially, in the interior. The fine clays of the Clyde probably belong to the latest stages of the Drift period; the sand and gravel mounds of the interior seem to be of older date. In accordance with the plan above proposed, I shall first describe the general character of the stratified Drift of the interior of the country, and then those of the lower districts. This arrangement, however, though it has a show of chronological order, must be confessed to be more one of convenience than of any well-founded systematic division.

1. Stratified Drift of the Interior.

Let the geologist conceive an undulating country with its valleys and hill slopes thickly covered with boulder-clay, or gravelly detritus, from which the bare rock either protrudes in knolls along the sides and summits of the hills, or rises above the plains into steep crags and isolated eminences. Let him imagine these valleys to be still further choked up here and there with mounds of shingle and sand, and the hill-sides to be dotted over at wide intervals with long banks and patches of the same material. Let him picture these banks and mounds running over wide moors, with now and then basins of fine clay, derived from the waste of the underlying till, and he will have some idea of the general disposition of the Drift throughout large tracts of Scotland.

As an illustration of the development of the marine Drift along the wider valleys, I may instance the great central valley of the country between the Clyde and the Firth of Forth. On the north side of the latter estuary it occurs as a chain of sand and gravel hills, extending from Largo Law up the valley of the Leven to the lake of that name, whence it stretches westward into the Vale of Devon. On the south side it occurs

throughout the Lothians in endless hillocks of gravel and sand and local patches of brick-clay. The deposits of sand and gravel are enormously abundant between Linlithgow and Falkirk. They likewise run westward in patches beyond Midcalder, and reappear on the west side of the water-shed of the country in a series of long sinuous ridges, which extends for miles across the Carnwath moors, and thence descends into the vale of the Clyde.

In many of the Highland valleys and glens, mounds and ridges of well-rolled gravel and sand likewise occur, often far removed above the present channels of the streams. Accumulations of this kind were observed by myself up the valley of the Dee to Balmoral, and they have been traced by Mr. Jamieson in detail all along the same valley, as well as along the Don, the Ythan, the Deveron, the Findhorn, the Spey, the Tummel, and the Tay. He finds, that in some cases the gravel shows an arrangement of its pebbles that appears to indicate the former existence of a current sweeping down the glens, a circumstance which is further indicated by the arrangement of the detritus in long ridges behind the lower ends of knobs of rock which look up the glens.

In more confined valleys the same prevalence of this sandy and gravelly drift is observable. Thus the depressions in which flow the Tweed and its tributaries, as the Biggar, Tarth, Lyne, and Eddleston Waters, are full of masses of water-worn detritus rising far out of reach of the present streams. The valley of the Clyde also, from where it leaves the Silurian uplands, is for several miles dotted over, sometimes almost barred across, with mounds and ridges of sand and gravel.

But the stratified Drift is by no means confined to valleys. It may be found in patches on the sides, and even on the summits of hills. Thus along the eastern flanks of the Lamberton Hills, between Berwick-upon-Tweed and Burnmouth, irregular mounds and coalescing ridges of gravel reach a height of 350 feet above the sea. Such ridges are abundant along the sides of the Lammermuirs and Pentlands, where there is no higher ground between them and the opposite sea. Some interesting examples likewise occur round the flanks of Tinto, especially

on the north side. Again, in Aberdeenshire, Mr. Jamieson has described a mass of water-worn shingle covering the top of a ridge of hills which extend from Buchan Ness for seven or eight miles inland, till they attain a height of 464 feet above the sea.¹ The same observer has traced stratified silt, believed by him to be marine, up to a height of 1550 feet on the flanks of Meal-Uaine in Perthshire.² A patch of gravel likewise occurs at a height of 1500 feet on Craigengar, one of the Pentland Hills. Stratified gravel and sand have been found by Mr. Jamieson, even as high as nearly 2000 feet in the Braemar mountains. But it seems doubtful if these are marine. No marine organisms have been found in any part of the Scottish Drift higher than 510 feet above the sea. The extreme height to which true marine Drift ascends has still to be fixed.

Even on the water-shed of the country, masses of stratified Drift may be found. Thus, between the Clyde and the Tweed at Biggar, there is a valley (650 feet over the sea) scarcely elevated above the level of the former river, and dotted over with heaps of sand and gravel, which rise high on the sides of the surrounding hills. The same feature is seen at Garvald and Dolphinton, where the ground which divides the Medwin (a tributary of the Clyde) from the Tarth (an affluent of the Tweed), at the height of between 700 and 800 feet above the sea-level, abounds in hills of fine white stratified sand. Up to nearly the crest of the ridge, between the sources of the Yarrow and the Moffat Water, rounded shingle may be traced to a height of 1000 feet above the sea.

Its Composition.—This division of the Drift is far less uniform in character than the boulder-clay, and presents no such intimate relation to the nature of the rocks on which it lies. It consists entirely of water-worn sediment, varying in texture from the coarsest shingle to the finest clay. It is usually stratified, but is singularly destitute of fossils. The coarser parts are sometimes devoid of any structure, and are piled together in ridges, mounds, and hillocks, like banks of gravel cast up by storms. But it is probably seldom that traces of stratification will not

¹ *Quart. Jour. Geol. Soc.* vol. xiv.

² *Op. cit.* vol. xvi. p. 362.

be found in some parts of these ridges. The coarse gravel is often interstratified with bands of sand, and the various beds go on interlacing with each other in endless lenticular layers. The sand is frequently full of diagonal lamination, and here and there contains a huge boulder where there is not perhaps another stone so large as a hazel-nut. Masses of pure white sand form groups of hillocks and ridges, as at Markinch in Fife, Mendick Hill in Peeblesshire, and Carstairs in Lanarkshire. With these deposits are occasionally associated thin beds and laminæ of clay, of a dull red, olive, or drab colour. Stratified clay, in thicker deposits, likewise occurs in hollows of the till, and is the common source which supplies our inland brick-works. It is usually devoid of stones; but in some places it contains them in such abundance as to approach in general aspect to the old till.

The nature of these strata can be advantageously studied in the Vale of the Clyde, and on the moory district between the town of Lanark and the border of Mid-Lothian. The river Clyde has cut through some deep masses of it in the neighbourhood of Carstairs, and exposed their structure in a line of cliff which is changing with every winter. The finely-stratified false-bedded appearance of the sands, the lamination of the clays, and the frequency with which these deposits are intercalated with each other, have been well brought to view by the operations of the river. A more careful search will show that some of the clay bands contain numerous stones, sometimes angular, and with one or more sides covered with striations. At Carstairs, the fine sand-beds of the railway cutting contain two or three large blocks of stone; and some of equal size, which have probably come out of the sand, may be seen on the margin of the Clyde, at the bend nearest Carnwath. In such cases, it is plain that the current, which gave rise to the fine lamination and counter-bedding of the sands, must have been wholly inadequate to the transportation of such large masses of rock. On the other hand, a body of water, which could hurry along these boulders, would assuredly have swept away the sand. The boulders must have been brought by some other agency—either that of coast-ice or of bergs. The exist-

ence of ice at the period of the deposition of these strata is still further shown by the scratched stones in the beds of clay, and by a remarkable contortion of the strata, to be immediately described.

The stratified Drift, in place of being spread over the surface of the country in a more or less persistent sheet, is gathered up into patches, sometimes of very limited extent, and sometimes covering an area of many square miles. Where it consists chiefly of sand or gravel, as it does over the greater part of the central valley, from the Firth of Clyde to the mouths of the Forth and Tay, it shows a remarkable arrangement into long confluent ridges, or into detached conical tumuli and hillocks. The resemblance of such cones of drifted sand and gravel to artificial mounds is so strong, that they are very generally regarded as true sepulchral heaps. But the stratified, and often diagonally laminated character of the sand, is sufficient proof that man has not had a share in their construction. That the mounds, however, have been used as places of burial does not admit of doubt. They are known in the Highlands as *tomhans*, the dwellings of a fairy race.¹ The long ridges are called in Scotland *Kames*, and are well exhibited in many parts of the Lowlands, as near Dunse in Berwick-

¹ Mr. Chambers in his *Ancient Sea Margins* satisfactorily shows that the mounds of Dunipace—so fruitful a source of conjecture to the antiquary—are of natural origin. It may serve to indicate, however, how strange and artificial is the aspect of such mounds of stratified Drift, that we find them everywhere regarded as the work of some earlier race of men or spirits. I could enumerate several instances where the existence of hills and ridges of sand in the south of Scotland has been for many generations popularly ascribed to the agency of Michael Scott, and his band of tributary imps. On the flanks of the Eildon Hills, for example, there is a series of sand ridges, such as are described in the text under the name of *Kames*. They are thus explained. A certain restless spirit had given the wizard no little trouble. He had to be kept in constant employment, and performed in this way the most marvellous feats, such as cleaving the Eildons in a single night. At last, Michael commissioned him to make ropes out of sand; but this task proved more than he could accomplish. He succeeded, indeed, in arranging the sand in long lines like the strands of a rope, but these fell in showers the moment he attempted to raise and twist them round each other. And to this day we see the lines of sand running down the hill-side, some of them broken and effaced where the hapless spirit had fruitlessly tried to entwine them. Scott alludes to this tradition in Note Z to the *Lay of the Last Minstrel*.

shire, at Loanhead in Mid-Lothian, in the Clyde Valley at Thankerton, and in Fife down the Vale of Leven. They occur also in Aberdeenshire. But the most wonderful display of them which I have yet seen lies in the moory tract of Lanarkshire, between Cleghorn and Auchengray.

Kames.—These curious ridges appear to be identical with the *ösar* of Sweden and the *eskers* of Ireland.¹ Considerable misapprehension has existed as to their structure, and hence some wholly untenable explanations have been offered as to their origin. They have been compared, for example, to moraines, and have been regarded as the traces of vanished glaciers. But this hypothesis is at once disproved by the situations which they frequently occupy in the middle of wide moors out of the reach of any glacier, by the water-rolled nature of their contents, and above all, by the fact that they are almost always stratified.

A kame may be described as a ridge of gravel or sand running in a more or less sinuous line, from a few yards to several miles in length, averaging perhaps from thirty or forty to fifty or sixty feet in height, and rising abruptly from the ground into a narrow crest. Such a ridge is often seen alone with no other mounds or ridges of detritus near it, keeping its course across a heathy flat like an artificial dam or rampart, and conspicuous from a distance not only by its form and size, but by the greenness of its slopes contrasting with the brown of the surrounding moor. I have never been able to trace any definite and persistent relation of these ridges to the form of the ground on which they occur.² Sometimes, as on the north flank of Tinto, the ridge begins on a hill-slope, and extends away into the plain. Sometimes it runs parallel to the hill-side, as below the west front of the beautiful cone of Quothquhan, near Thankerton. Again, it may be seen rising up in a flat moor apart from any rising ground, as is admirably

¹ See Sir Charles Lyell, Paper on the Scandinavian *Osar*, *Phil. Trans.* 1835, p. 15, and Mr. Jukes on the Irish *Eskers*, in the second edition of his *Manual*.

² Mr. Milne-Home remarks that in the east of Scotland the kames have a general east and west direction, *Brit. Assoc. Rep.* 1861, p. 115. But I could cite not a few examples where the direction is more north and south.

shown on the Carnwath moors, and on those to the south of Dirrington Law in Berwickshire. I have frequently observed, however, that these ridges run across valleys, and have been cut through by the streams. Examples may be seen in the Clyde Valley at Thankerton, and at the junction of the Douglas Water, in the course of the Mouse Water (a tributary of the Clyde) near Ravenstruther, in the grounds of Dunse Castle, on the moors between Dunse and Westruther, and in many other localities. Yet other instances might be cited where the kames run along the line of the valley, especially if it be a wide and tolerably flat one. This may be verified in the course of the Medwin above Ogscastle, and on a much greater scale in the wide valley traversed by the Caledonian Railway between Auchengray and Carstairs. When we consider the nature of their contents, it seems hardly possible that these ridges have no dependence upon the form of the ground. I believe there must be some general relation which has hitherto escaped observation, but which, when discovered, will be found to connect them satisfactorily together.

But the kames are not always solitary mounds. In some districts they ramify into different branches, often coming together again so as to form basins, which, having for the most part no outlet at the surface, are either the site of peaty marshes, or of small lakes. This form of ground is illustrated in a remarkable manner round Carstairs. A well-formed kame begins in the moors beyond Carnwath, and, after running for upwards of two miles in a sinuous course, with here and there a short spur running out on either side, and with one or two lateral basins, merges into a group of confluent ridges, which continue in the same direction for more than three miles farther. Those



FIG. 4. — Sectional outline of sand and gravel mounds at Carstairs, Lanarkshire. (The dark layers in the hollows are deposits of peat.)

ridges are connected together by transverse bars at irregular intervals. Hence there results a net-work of anastomosing sand

bars and mounds, enclosing an endless succession of basins, from two or three feet, up to two or three hundred yards in diameter, and their bottoms sometimes sixty or eighty feet below the crest of the surrounding ridge. These hollows are, in three or four instances, occupied by water; more commonly a flat, peaty bottom marks where an ancient lochan has been. They lie at many different levels in the range of sand mounds; indeed, in this respect they appear to be each independent of the others. It is a singular scene which lies spread out before the observer when he places himself on one of the higher eminences among this rolling group of hills. Here and there his eye rests on the dark peaty hollows, from which the green grass-covered mounds rise up sharply, and sweep away to the north-east in undulating succession. Beneath him, perhaps, lies the solitary little tarn called the White Loch, its sides as steep and circular as one of the crater-lakes of the Eifel. Far away to the north and west stretches a wide flat moor, from which the sand-hills start up like lines of rampart. He feels that somehow it is but the model in miniature of a great mountain scene on which he is looking. The lines of valley, the lakes, the deep enclosed corries, the lonely moorlands, and the rolling hills are all there, but they are dwarfed into a pigmy size.

A kame consists almost entirely of sand or gravel, varying in texture from the finest grain up to a coarse aggregate of boulders. These materials, except in rare cases, are stratified. They often alternate with each other in rapid succession; thin layers or laminæ of sand are intercalated in the gravel beds, and occasional seams of gravel vary the stratification of the well-bedded masses of sand. The sands, moreover, are as a rule full of diagonal lamination or current bedding. It seems plain, therefore, that currents of water must have played some part in the accumulation of these sedimentary deposits. This is still further shown by the occasional introduction of thin lenticular seams of laminated clay.

In Lanarkshire, I have found two well-marked classes of kames—1st, Those which consist wholly, or nearly so, of coarse shingle; and 2d, Those that are made up of fine sand and gravel. The shingle kames are usually sharper and higher in outline

than the others. Their component gravel is either stratified very rudely, or not at all. The stones are usually well-rounded, and vary in size up to blocks four or five feet in length, which, in one or two instances, I found polished and striated. The striæ, however, were less sharply retained than upon stones in the boulder-clay. A good illustration of this form of kame is shown in the neighbourhood of Carstairs, where the Mouse Water has cut through a long sharp ridge of gravel, and laid bare a section of it on both sides of a broad water-course. The eastern bank is a high steep cliff formed by the cutting through of the kame. A mass of very coarse unstratified well-rounded gravel is there laid open, rising up into the conical mound which makes the kame, and overlaid on its south-side by a series of finely-laminated clays and sandy beds. These latter strata point to a time of quiet deposition, for the clay splits up into thin layers like the leaves of a book. They rest against the slope of the shingle bank, which thus seems to have undergone little alteration since the time of their deposition. The mode of accumulation of the gravel, however, is a question of no little difficulty. That ice has been in some way or other concerned in the process, I do not doubt. The mere striation of the stones seems to place this beyond dispute. The size of some of the blocks, too, favours the idea that they were helped along by the carrying power of ice. Moreover, on the west side of the river, the same ridge of coarse gravel shows here and there in its mass thin layers of sand, and at least one lenticular seam of fine olive-coloured clay. Had the heaping together of such blocks been done by the transporting agency of a powerful current, or by a set of strong tides, we might expect that there would have been some definite arrangement of the whole mass in lines of bedding. It is not easy to see how, by such agencies alone, the gravel should have been huddled tumultuously together, with here and there nests and layers of stratified sand and clay. When the true solution of the origin of these perplexing ridges is discovered, we shall probably find it a complex one, involving the operation not only of the tides and currents of the sea, but of drifting ice; perhaps, too, in some cases, of the floods caused by melting snows, and pos-

sibly of some other agent whose concurrence we do not at present suspect.

The second form of kame consists of mounds of sand, or of sand and gravel in well-stratified beds. These strata present a convex or dome-shaped arrangement; they are heaped over a central nucleus of the same materials, and it is the upper

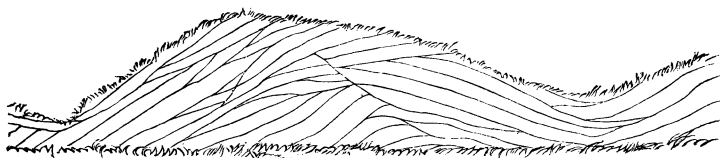


FIG. 5.—Section of a Kame laid open on the line of the Lanark and Douglas Railway.

surface of the outer bed which defines the outline of the Kame. Where this outer bed consists of a layer of gravel, the ridge is usually sharper and better preserved than where loose sand has formed the surface. Thin beds of clay, sometimes finely laminated, are occasionally to be observed even among the densest masses of sand and gravel. Neither in these clays nor sands has any trace of an organism yet been found. Some interesting sections have recently been exposed through this series of Drift-beds, by a cutting of the branch railway from Cleghorn to Douglas. But I reserve a full description of them for a future number of the *Memoirs of the Geological Survey*.

The perfect stratification and diagonal arrangement of the sand in this form of kame, the minuteness of lamination in the occasional clay-seams, and the grouping of the whole series of layers, one over the other, into a conical mound, seem to disprove any hypothesis which would explain these ridges as the result of a violent rush of water.¹ These structural characters rather indicate a slow and long-continued process, in which currents from different quarters, and laden with various kinds of detritus, took a large share. Two currents coming from opposite directions, and each charged with sediment, would deposit a part of their burden along the line of their junction. But it is often difficult to understand from the existing form of the ground where the

¹ See, for example, Mr. Milne-Home, *Rep. Brit. Assoc.* 1861, p. 151.

kames occur, how two such currents could have been produced, and how, above all, they should have dropped their loads in such places as we now find the kames to occupy.

The kames, whether of unstratified shingle, or of well-bedded gravel and sand, merge imperceptibly into a wide expanse of undulating ground, the uneven surface of which results from the unequal deposition of the same materials of which the more marked ridges or kames are formed. It is, in short, a tract of gravelly and sandy detritus, which is in some parts heaped up into long well-defined mounds.

Brick-clays.—These occur usually in hollows of the boulder-clay, and coincide in colour with the local changes which that deposit undergoes. They are usually well stratified, the layers being sometimes as fine as the leaves of a book. Though commonly to a large extent free from stones, they here and there contain them in such quantities as to approach in general aspect to the old boulder-clay. These stones, moreover, are occasionally striated, and it is sometimes possible to follow them to their original sources.

In the interior of the country I have never been able to trace these clays, except over very limited areas. Along some of the lower or maritime districts, however, as will be pointed out in the succeeding pages, they appear to have been deposited in much more continuous sheets. In these localities, too, they have yielded molluscan remains in abundance, but in the inland districts, so far as I am aware, they have not yet afforded an organism of any kind.¹

The brick-clays may be found interstratified with the Kame group of beds; the whole forms therefore one series of deposits.

¹ Mr. Milne-Home, in his paper on the Parallel Roads of Lochaber (*Trans. Roy. Soc. Edin.* vol. xvi.), mentions the occurrence of a bed of peat one foot thick, with imbedded roots of trees resting on a fine silt, and covered by ten feet of sand. This deposit was seen in a railway cutting between Edinburgh and Newhaven, and lay between seventy and eighty feet above the sea. It is uncertain whether or not it should be classed with the drift now under review. Possibly when the land stood seventy or eighty feet lower than now, the peat was forming close to the shore, and was buried beneath a mass of sand driven up either by the waves or by the winds. Mr. Milne-Home mentions that the peat contained roots apparently of the hazel, with stems of reeds and other marsh plants, and seeds like those of a species of whin.

In some localities where this union of sands and fine clays is exhibited, there occur some of these curious contortions of the bedding which are characteristic of the Drift of the Norfolk coast.

Contorted Bedding.—Sir Charles Lyell was the first to observe the occurrence of contorted beds in the stratified Drift. Between the South Esk and the Prosen, some stratified gravels and sands were found by him to be so disturbed, that a perpendicular shaft might intersect the same beds three times. The red boulder-clay below had not suffered, and some of the contorted beds were overtopped by others perfectly horizontal, showing that the disturbance took place during the deposition of this series of strata.¹ The best illustration with which I am acquainted, is one which may be seen on the north bank of the South Medwin Water, a short distance above the confluence of that stream with the Clyde. Its features will be understood from the accompanying figure. The bed of stony clay on the

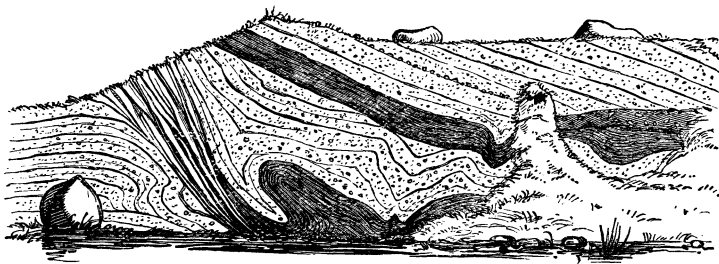


FIG. 6.—Section of contorted beds of sand and clay. Medwin Water.

right-hand side of the section, presents several points of interest. Its enclosed stones are subangular and rounded; they vary in size up to a foot or eighteen inches in length, and abound in striated surfaces. The great majority of them consists of various felstones, with some pieces of Silurian grit—rocks which are found in places immediately to the south, on the high grounds that rise from the south side of the valley of the Medwin. The locality of the felstone is unmistakable. These scratched

¹ *Proc. Geol. Soc.* vol. iii. p. 341.

stones must then have been transported from the hills above Biggar across the Medwin valley. I am by no means sure, however, that this layer of stony clay is not a cake of the true till, which, frozen into a mass of ice on the Biggar hills, was borne across the sea-strait that once covered the low grounds of the Medwin, until it was dropped on the spot where we now find it. But in whatever way they were carried, the course of the stones was certainly northward, and the place of their departure can still be approximately fixed. Nor is this all. Here and there over the surface, and sometimes in the interior of the mounds of drift, of which the preceding woodcut gives a section, large blocks of a red pebbly sandstone or fine conglomerate may be seen. These are so altogether out of proportion to the little pebbles which the sand-beds contain, that they plainly do not owe their transport to the ordinary drifting operations of marine currents. They too must have been ice-borne. Nor do we require to look far for their source. Not much more than a mile to the north-east, there is a long bare hill, to which allusion has been made on a previous page, composed of the same Old Red pebbly sandstone and conglomerate, which protrudes at many places in loose blocks of all sizes. I do not doubt, that when the land stood about 800 feet lower than it does at present, coast-ice formed in sheets along the sides of this hill, and that masses of it, into which blocks of the rock had been frozen were broken off, and carried their burden over the sand-mounds to the south-west.

The striated boulders of the stony clay and the large blocks on the surface, bear each their testimony to the former presence of ice-rafts which drifted across from the high grounds on the south and north sides of the strait. The crumpled appearance of the strata depicted in the figure corroborates this testimony. The fine beds of clay, fairly bent back upon each other, may be traced curving round into a sharp loop, and then into another equally abrupt, after which they go waving along until they are lost under a mass of turf and debris. A line perpendicular to their plane of bedding, would thus, in the course of two or three feet, intersect them thrice at nearly a right angle. Such contortion must be due to powerful pressure. It may have been produced by a mass or masses of ice standing here and pushed

onward for some way over the yielding sand, partly by their own impetus, partly by the action of winds or currents. The compression to which such a weight of ice would give rise, would probably be quite sufficient to corrugate beds of clay and sand, of which the cohesion could not be great.¹

Erratic Blocks.—Scattered over the surface of the country, sometimes on the bare rock, sometimes on the boulder-clay, and sometimes either on or in the stratified Drift, are numerous blocks of stone which do not belong to the rocks immediately around them, but which have been carried from greater or less distances.² It is a common error to associate these blocks with the boulder-clay, and consequently to speak of that deposit as an erratic one. But I have already shown that the stones of the boulder-clay, in the vast majority of cases, have not been derived from any other rocks than those of the surrounding district. The blocks now to be described are to be considered as contemporaneous in their transport with the deposition of the stratified Drift. They belong to a time when the present land was in great measure beneath the sea, when glaciers still lodged in the recesses of the mountains and descended to the sea-level, and when bergs and coast-ice, drifting over the submerged hills and valleys, carried away the blocks of one district and dropped them upon another, perhaps fifty or sixty miles distant. Hence, though such boulders are most obtru-

¹ See Lyell, *Proc. Geol. Soc.* vol. iii. p. 171.

² There are some districts where the number and size of the erratics have given rise to the wildest legends of warlocks and elfins. Such a locality occurs between Carnwath and the river Clyde. Here, before farming operations were carried to the extent to which they have now arrived, large boulders, now mostly removed, were scattered so abundantly over the mossy tract between the river and the Yelpling Craig, about two miles to the east, that one place was known familiarly as "Hell-stanes Gate" [road], and another "Hell-stanes Loan." The traditional story ran that the stones had been brought by supernatural agency from the Yelpling Craigs. Michael Scott and the devil, it appears, had entered into a compact with a band of witches to dam the Clyde. It was one of the conditions of the agreement that the name of the Supreme Being should never on any account be mentioned. All went well for a while, some of the stronger spirits having brought their burden of boulders to within a few yards from the river, when one of the younger members of the company, staggering under the weight of a huge block of green-stone, exclaimed, "O Lord, but I'm tired." Instantly every boulder tumbled to the ground, nor could witch, warlock, or devil move a single stone one yard further. And there the blocks lay for many a long century, until the rapacious farmers quarried them away for dykes and road-metal.

sively seen when lying on the surface of the ground, especially along a bare heathy hill-side, they may also be found occasionally imbedded among the stratified sands and clays which were formed during the same period of submergence. Examples of this kind have just been given, and others will be cited from the stratified Drift of the maritime districts. It would indeed be easy to multiply such proofs that the true erratic blocks which are strewn over the country must not be classed with the boulder-clay, but with the deposition of the stratified Drift. The transporting agents have not been glaciers, but masses of ice borne across the sea.

These erratics are not thrown down wholly at random across the face of the island. It is easy to trace, that in at least some districts they have radiated from the main mountain masses towards the plains. Thus, to the south-east of the chain of the Grampians, blocks of mica-schist, clay-slate, gneiss, and granite, may be followed sometimes for fully fifty miles. If we glance at a map of Scotland we see that the south-eastern margin of these mountains descends into a wide valley, on the further side of which runs the line of the Sidlaw, Ochil, and Lennox hills. Now this chain of heights has intercepted a large number of the rock-laden masses of ice which were carried out from the Grampian shores. The blocks are found in great abundance along the north-west fronts of the hills, that being, of course, the side which faced the direction whence the bergs came. Sir Charles Lyell has described some striking examples from the Sidlaw range. Thus, on Pitscanly Hill, at a height of about 660 feet above the sea, he found a block of mica-slate thirteen feet long, seven broad, and seven in height, above the ground. One of the nearest points at which the rock occurs *in situ* is fifteen miles distant, and between the localities intervenes the great valley of Strathmore, and the hills of Finhaven.¹

But some of the bergs appear to have found their way, either across this range of hills, when it may have been in great part or wholly submerged, or through gaps such as that at Stirling in which flows the Forth. Blocks of some of the metamorphic rocks of the Highlands have been observed on the flanks of the Pentland Hills. One described by Mr. Maclaren, stands about

¹ *Proc. Geol. Soc.* vol. iii. p. 344.

1020 feet above the sea, and may be computed to weigh about eight or ten tons. In the same neighbourhood I have noticed some smaller blocks of white quartz-rock. According to Professor Nicol, similar erratics have even been seen on some of the Silurian uplands of Peeblesshire. These boulders cannot have travelled less than fifty or sixty miles. They must have been carried from the Highland mountains, either through or over the range of the Lennox and Ochil hills, and across the deep valley of the Forth.

Mr. Hopkins has observed a similar dispersion of erratics from the high grounds round Ben Cruachan.¹ He found blocks of granite in the beach at Oban, and in considerable mass to the northern extremity of the island of Kerrera. A large number of similar boulders occur on the shores of Loch Lomond, Loch Long, and Loch Fyne. These, he supposed, might have come from a granitic tract in the immediate vicinity of Loch Sloy, at an elevation of from 1500 to 2000 feet. They are dispersed along the sides of the valleys to the height of 300 or 400 feet. One large boulder of granite may be seen much farther to the south, on the shore of Bute, near the Point of Ardmaleesh. I am not aware of any granite from which this block could have come nearer than that of Ben Cruachan, which is thirty-five or forty miles off in a straight line, with several intervening deep valleys, such as that of Loch Fyne, and some ranges of high ground including the mountainous tracts of Cowal.

The erratics of Bute have all come from a northerly source. On the slate hills of that island blocks of mica-schist, quartzose grit, and gnarled gneiss are not unfrequent,—all these rocks occurring in great mountain-masses a few miles to the north. The direction of transport, however, is still more convincingly shown upon the southern half of the island, which consists of red sandstone, with some outliers of igneous rock. Over this tract blocks from the metamorphic regions to the north are profusely scattered, but a fragment of sandstone is never, I believe, found to the north in the slaty and schistose districts.

The beautiful valley of the Girvan at Dailly is strewn with

¹ Reports of *Brit. Assoc.* for 1850, and *Edin. New Phil. Jour.* vol. xlix. 334, vol. liii. 362.

blocks of granite. These may have come across from Arran, though it is perhaps more probable that they were brought down from the granite tracts of Galloway, which stretch away southward from lonely Loch Doon. The granite of Criffel is found a long way to the south among the boulder Drift of the northern and western counties of England.

I need not multiply instances of a phenomenon so familiar. They may be found in almost every part of the country. There are one or two additional points of interest, however, connected with the dispersion of erratics, to which a brief reference may be made.

In the first place, it is occasionally possible to trace these blocks for some distance in lines, as if they had been dropped at intervals by a mass of ice which was moving steadily in one direction. Sir Charles Lyell has referred to a continuous stream of boulders and pebbles, traceable from near Dunkeld by Cupar and Forfar, to the sea at Lunan Bay—a distance of nearly forty miles.¹ On the Pentland Hills, Professor Nicol thought he could trace the erratics in “broad bands, running nearly in straight lines, from NNW to SSE, without any reference to the present declivity of the ground.”² A beautiful example of the same kind may be seen on the crest of Cairngryfe Hill to the north of Tinto. This ground is probably not less than 1000 feet above the sea. The hill runs as a long ridge in a NE and SW direction, and shows, in many places, its pink felspar-porphyry protruding from under a scanty covering of turf. Over this bare surface run two lines of blocks of hard white sandstone. These stones vary in size, from a mass containing fifteen, to one comprising forty cubic feet. Hence they may be assumed to average about two or three tons in weight. There is no rock like this for many miles round. It is evidently a carboniferous sandstone, yet the blocks are at a much higher level than any of the carboniferous rocks of the surrounding districts. When I found these erratics, I felt considerably at a loss to account for their position and to guess at their source. Before I quitted the hill-top, however, a distant

¹ *Proc. Geol. Soc.* iii. p. 342. This instance, however, may perhaps more fitly be classed with some of the phenomena of the kames.

² *Quart. Jour. Geol. Soc.* vol. v. p. 22.

gleam of sunlight fell over the uplands of Ayrshire, and brought out in relief, against the western sky, the summit of Cairn Table, which rises nearly 2000 feet above the sea. I was familiar with the peculiar white quartzose sandstone forming the upper part of that hill, and on looking again at the texture of the erratics, I was struck with their resemblance to the Ayrshire stone. The distance of the two localities is about 17 miles, in a north-east and south-west line. A few days later, on again crossing this line, a few miles to the south-west of Cairngryfe Hill, I found another irregular stream of similar blocks. It seems to me highly probable, therefore, that these fragments of hard white sandstone have been ice-drifted from the high grounds round the sources of the Ayr, and carried in a north-easterly direction so as to be dropped in long lines over the moors and hills of Carmichael.

Another question of not a little interest is the height to which erratics ascend above the present sea-level. Mr. Jamieson mentions that in Braemar he has seen transported boulders on hill-tops more than 3000 feet in height, and in Perthshire up to elevations exceeding 2000 feet. He regarded these at the time as having probably been carried by drifting ice. If this be their true explanation, it follows, of course, that the land during its submergence must have been 3000 feet lower than it is now. But it is, perhaps, possible that these blocks may have been transported from one hill to another by land-ice during the general glaciation of the country. Although foreign fragments occur up to a height of 3000 feet, none are found on the tops of the granite mountains of the Ben Muic Dhui group, which attain elevations approaching 4000 feet.¹ This, of course, does not prove that these high grounds were not submerged, but it harmonizes well with the supposition that they were wrapped in a mantle of ice which spread over the hills of lesser height, and bore onwards the blocks which fell upon its surface from such precipices as that of Lochnagar. Again, near the top of Tinto, which is more than 2300 feet high, I have found pieces of carboniferous sandstone and greenstone; but these, I do not doubt, are relics of the boulder-clay. They are all small, and are mixed with abundant fragments of the red felstone of the

¹ Jamieson, *Quart. Jour. Geol. Soc.* xvi. 367.

hill and the dull reddish or greenish grits and conglomerates of the district.

There is no question connected with the deposition of the marine Drift which more requires a careful investigation than the extent to which the land was submerged during that part of the glacial period. That all the ground below 2000 feet was under water I think highly probable. With regard to higher elevations, though I am very far from denying their submergence, I do not think any satisfactory proof of the fact has been yet put on record. Mr. Jamieson will, I trust, before long be able to put this matter definitely at rest.

Lastly, erratics are sometimes found at a considerably greater altitude than the rock from which they have been derived. It is possible, indeed, that some of the recorded instances may be referrible rather to the time of the general glaciation than to that of floating bergs. Thus boulders in the till, or lying on the surface but evidently washed out of that deposit, I have often found at higher elevations than their parent rock. The motion of a great sheet of land ice from the higher parts of the country to the sea would be sufficient to carry such boulders down into valleys and up again to the tops of such hills as were enveloped beneath the icy flow. But in the case of large angular erratics, more especially such as lie upon stratified Drift high above their original source, the most probable explanation is that which supposes that they were drifted about from coast to coast during a depression of the land, or that they were pushed up above high-water mark by the grinding of the floes, that they thus remained at the sea-level while their parent mass was carried down below it, and that they were finally stranded, and thus when the land rose again they lay far above their original site. Such a hypothesis would involve oscillations of level during the general movement of upheaval which characterized the epoch of the marine Drift. This, therefore, is a subject which well deserves the renewed attention of geologists.¹

Origin of the Sandy and Gravelly Drift.—Before quitting the subject of the Drift of the interior of the country, some remarks may be offered upon the circumstances under which it was formed. I have already stated the probability that its accumu-

¹ See Darwin, *Quart. Jour. Geol. Soc.* iv. 315, and the authorities cited by him.

lation went on during the re-elevation of the land, and that coast-ice must often have had a share in transporting at least the heavier parts of its contents. I believe the greater part of this Drift, though it is unfossiliferous, to be of marine origin. Its occurrence on water-sheds, or on the sides of mountains and hills far out of reach of any stream, seems sufficient evidence that in such cases fluvatile action must have been impossible. And in these situations the mounds of sand and gravel are exactly comparable with others which occur in lower parts of the country. It is difficult, therefore, to avoid regarding the whole as due to the operation of some one general agency. This agency was, in all likelihood, the waters of the ocean.

It may, perhaps, be possible eventually to show that there are certain levels at which the amount of stratified Drift is much greater than at others. If a persistent band of sand and shingle could be traced at one general height round the island, it would afford good evidence of a long pause in the upheaval of the land. Something of this kind seems to be indicated by the masses of sand and gravel which wind round the base of the hills on the confines of the counties of Peebles and Lanark from Dolphinton southwards to the water-shed between the Clyde and the Tweed. The sand-hills between Mendick Hill and Dolphinton reach a height of about 900 feet; those lining the hollow between the Clyde at Symington and the Tweed at Rachan ascend the slopes to a height of 820 feet. The wide range of sand and gravel ridges on the Carnwath moors are between 700 and 800 feet above the sea. But this district is at present under investigation by the Geological Survey, and this point will be examined in the course of the ensuing summer. Such traces of actual sedimentary deposits along well-defined contour lines would be more satisfactory evidence of pauses during the rise of the land than evanescent terraces of erosion, which, being only well marked close to the sea-margin, become fainter as they ascend above that level. Such terraces depend, for their prominence, partly upon the nature of the material opposed to the action of the waves, partly also upon the length of time during which they have been subjected to that action. The non-existence of the terraces, therefore, would by no means invalidate the conclusion as to a general submergence of the land. It might

merely indicate that the upheaval had been comparatively rapid, or had not been marked by long pauses at successive elevations. Again, the greater distinctness of one terrace as compared with others, cannot of itself be regarded as proving a longer sojourn of the sea-margin at that particular level. The prominence might be due as much to the recentness of the up-rise, or to the nature of the material, whether Drift or rock, acted upon by the breakers, or to the absence of runnels and streams by which the terrace might have been more or less effaced. Mr. Chambers has ingeniously traced a number of lines along the surface of the island which he regards as marking successive pauses during the re-emergence of the land.¹ The evidence for the identity of these lines with ancient beaches would be more satisfactory if they were more frequently found to retain traces of littoral deposits.

The deposition of the marine Drift would be greatly affected by the manner in which the land rose. If this elevation proceeded by slow stages, separated by long pauses, there would be produced the lines of old beach just referred to. If there were no pauses, these lines would be absent, and the Drift would be scattered over the surface as it was left by the retreating tides. If, on the other hand, the rise proceeded by jerks or sudden uplifts, the backward recoil of water would undoubtedly produce powerful effects in sweeping away loose detritus, and heaping it up in sheltered places, or along the line of impact of two opposing currents. It is by such an explanation that Mr Milne-Home and Mr. Jamieson would account for some of the long gravel ridges in different parts of the country. In some of the Aberdeenshire valleys, described by the latter observer, the gravel is arranged in such a way as to indicate the outward passage of a strong rush of water. It is often swept out of the narrower parts of glens, and in other places is arranged in ridges behind knobs of rock which look up the valleys. Mr. Jamieson suggests that during a rapid rise of the land or a series of elevatory shocks, the sea-waters rolled back, scouring out the glens, and heaping up sand and gravel in the lee of the opposing rocks.²

¹ *Ancient Sea Margins*, 1848.

² *Quart. Jour. Geol. Soc.* xvi. Milne-Home, *Brit. Assoc. Rep.* 1861. Sect., p. 115.

This explanation may account in part for the arrangement of the loose detritus in the Highland glens. It seems to me, however, that we must also take into account the possible freshets and floods which would arise whenever the covering of snow and ice in the higher parts of the country was rapidly thawed. Such vast bodies of water suddenly disengaged down the narrow valleys would produce many of the effects just described. Perhaps the true key to the origin of much of the Highland detritus lies in the adoption of both these hypotheses. In the next section of this memoir, I shall point out that the volume of water filling the Scottish rivers was, in all likelihood, very much greater during the later stages of the Drift period than it is now.

2. Stratified Drift of Maritime Districts.

Clay-beds of the Clyde.—These deposits have been classic ground to the geologist ever since Mr. Smith of Jordanhill announced the remarkable character of their fossil contents. They occur along the basin of the Clyde, on the low grounds that flank the river from the neighbourhood of Glasgow down to Greenock, beyond which they may be detected in most of the sheltered bays of the Firth. They fringe parts of the margin of Loch Lomond, and lie on some of the little islets of the lake. One of Hugh Miller's last geological excursions was devoted to tracing them between Loch Lomond and Stirling, and he succeeded in finding them at Bucklyvie. Along the shores of the Holy Loch, on the opposite coast at Gourock, and southward at Fairlie, all through the Kyles of Bute, and in every inlet of that island, in Loch Fyne at Lochgilphead, they may readily be found. The same deposits occur also on the west side of the Argyleshire peninsula at Oban, and northwards still, on the margin of Loch Eil, at Fort-William. Indeed, there is reason to believe that they extend under the bed of the Atlantic along the whole of our western coasts.

They are in most cases of a very fine texture, like consolidated impalpable mud. Beds of this description may be seen fifteen or twenty feet in thickness, without a single stone or shell. Above them lie other clays also fine in texture but containing shells and stones, with here and there a boulder, some-

times covered with striations, or mottled with serpulæ and barnacles, while in other localities the shells or the stones, or both, increase in number till they compose a considerable part of the bed. But even where they are most abundant the clay remains, as a whole, of the same fine texture, so that when the stones and shells are picked out it can be used for brick-making. These shells, as will be seen in the sequel, point to a much severer climate than that which now characterizes the area of Britain.

Along the higher reaches of the Firth of Clyde above Greenock, the stratified clay-beds occupy the low grounds bordering the river, and they never, so far as I am aware, reach a greater altitude than fifty feet above high water-mark. They are extensively used for the purposes of brick-making, and may be studied with facility in the clay-pits at Paisley and Houston. In making a recent excavation for a gasometer at Paisley, the following beds were passed through in descending order. For their description I am indebted to the Rev. W. Fraser, Paisley.

1. Dark earthy soil, passing down into gravel and sand, interspersed with stones, and containing two boulders, one of which was of great size, 3 feet 6 in.
2. Sandy clay without large stones, and containing no shells, . . 4 " 6 "
3. Thick bed of fine clay, interspersed with *Tellina proxima*, *Cyprina Islandica*, *Modiola modiolus*, *Pecten Islandicus*, *Trophon clathratum*, etc., and containing a good many angular stones, none of which were observed to be striated, . . . 13 " 0 "
4. Laminated clay not pierced through, but so far as examined it contained no shells.

Mr. Fraser informs me that here and there, at various depths, in bed No. 3, he found bands of shells, particularly the *Mytilus edulis*, crowded thickly together and perfectly preserved. The stones were often as angular at the edges as if recently broken, but never showed striations. They consisted of carboniferous limestone (containing *Rhynchonella pleurodon*), quartzose sandstone, micaceous and red sandstone, ironstone, basalt, and quartzose schist. It is worthy of remark that nearly the whole of these stones may have come either from the south or the east; the geological formations of which they are fragments do not lie to the north or west. On many of them, as well as on the large horse-mussels, *balani* were noticed. My informant

remarks that he also observed dark lines of earthy or rather carbonaceous matter stretching out from some of the stones, and apparently indicating the presence of sea-weeds attached to them.

From the same neighbourhood the Rev. Mr. Crosskey has kindly measured for me the subjoined section of the same clay-beds:—

- | | | |
|--|-----------|--------------|
| 1. Alluvial soil, | | 4 feet 0 in. |
| 2. Littoral sand and gravel, with <i>Cardium edule</i> and pieces of wood bored by <i>Teredo</i> , etc., | | 0 „ 9 „ |
| 3. Clay without shells, | | 6 „ 0 „ |
| 4. Fine brick clay, with shells (a bed of <i>Cyprina Islandica</i>), not pierced through. | | |

Below both these sections, at a short distance, lies the stiff boulder-clay of the district. When I visited the clay-pits of this neighbourhood in September last, I found in one of them that the stones of the shell-clay were sometimes well rounded and smoothed like beach stones, and in one instance beautifully striated. Mr. Crosskey has since obtained several well-scratched boulders from the same clay, but they are certainly not common.

In the line of the Greenock and Glasgow Railway, a section was cut through a hill between Greenock and Port-Glasgow, in which Mr. Smith of Jordanhill found the following beds in descending order:—

1. Vegetable soil.
2. Coarse gravel, two feet.
3. Sand, ten feet. In neither of these strata did any organic remains occur.
4. A series of thin beds of sand, gravel, and clay, full of sea-shells. In this group he found thirty-three species.
5. Boulder-clay, of unknown depth.

These shelly beds lay about fifty feet above the level of the sea. Of the shells nearly a half were species not known to be living in the adjoining seas, but confined to much higher latitudes.¹

Below Greenock the shell-clay is found between tide-marks at Gourrock Bay. From this point down the Firth, its usual situation is on the beach, and only where the ground is low

¹ *Researches*, p. 32. I do not think it necessary to give lists of the shells in the text, as I have added to this paper a full catalogue of all the species which have been detected in the Scottish glacial beds up to the present time.

towards the shore does the clay extend inland. Along the greater part of the coast-line of the Firth of Clyde the land rises somewhat abruptly from the level terrace of the twenty-five foot raised beach, and the cliff which is thus formed has effectually prevented the clay from rising into the interior. In some localities, as at Balnakeallie Bay in the Kyles of Bute, the clay runs up from the beach for a short way into a creek of the shore. Here the singular contrast may be seen of a limpid streamlet running over the clayey bed of an old ocean, and washing out the shells that still lie in the positions in which they lived and died. In other places, where the ancient cliff-line sinks down into a low level flat, the clay is sometimes found in sinking wells or foundations, at a distance of a mile or more from the sea. It is, I believe, in this situation that it occurs in the neighbourhood of Stevenston in Ayrshire, where the ground is pierced for a coal-pit shaft.

In most of the less exposed bays and inlets of the Firth, the shell-clay is probably to be met with. In one or two places, as at Ettrick Bay on the west side of Bute, I have seen it apparently in its last stage of decay. It had evidently, at one time, covered the whole beach, but it was washed off everywhere except under the lee of the scattered stones and boulders which had screened it from the waves. Along those parts of the shore where such boulders are absent, its destruction has probably been accelerated. At extreme low-water, it may be seen in many places on the Bute coast descending beneath the sea, though all trace of its existence has disappeared from the higher zones of the beach. In such localities the characteristic shells of the glacial period may be seen crowding the surface of the clay, and intermingled with the exuviae of the living denizens of the Firth. The shells are often lying in the position in which they lived. This is especially to be noticed in *Mya Uddevallensis*, which, at extreme low ebbs, may be seen in scores standing upright in the clay as if it were actually the contemporary of the *Mya truncata*, which is still living in the same place, and bores into the same clay among its ancient congeners.

The occurrence of this shell-clay along the margin and the bottom of the sea, gives rise to two risks of error in observa-

tion. In the first place, the geologist who examines it on the shore requires to use the most scrupulous caution lest he include as fossil species shells which have been recently introduced into the clay by the action of the tides. I cannot but think that the list of glacial shells from the Clyde has been in this way unconsciously increased. And I could not have believed that the chance of error was so great, had I not had the good fortune to be guided over the deposits by my friend, the Rev. A. Macbride, of Ardmory, who has spent many years in quietly but sedulously exploring the glacial clays of his own neighbourhood. The other source of mistake is open to the naturalist, but is by no means so likely to mislead. In dredging over a part of the sea-bed, where glacial deposits containing shells occur, there is sometimes a tendency to forget their existence. Fresh-looking valves of *Tellina proxima* and *Pecten Islandicus*, for example, are thus dredged up along with living shells from the same sea-bed, and unless the existence of the shell-bearing clays is kept in view, there is some danger of classing together, as contemporaneous, the organisms of two very distinct and widely separated periods in the geological history of the country.

The best section of the stratified clays which I have seen in the Clyde basin occurs at the Kilchattan tile-works in Bute, only a few feet above high-water mark. There the following beds are seen in descending order:—

1. Vegetable soil.
2. Sand and gravel, well-stratified, false-bedded, passing down into a sandy clay with gravel, 10 or 12 feet.
3. Red clay without stones or shells, becoming dull olive green in lower part, 1 to 2 feet.
4. Bed of fine dark clay, full of *Tellina proxima*, etc., many of the shells retaining both valves, 2 feet.
5. Finely laminated brown and reddish brick-clay, without stones or shells, 15 to 18 feet.
6. Hard tough red boulder-clay with striated stones; its upper surface hummocky and irregular.

The boulder-clay is of a red colour, and has a lumpy uneven surface on which the finely-laminated brick-clay rests. This brick-clay is entirely free from stones, and may be split up into thin layers indicative of a tranquil deposition. The shell

clay is not laminated, but is exceedingly fine in texture. The shells abound, especially the *Tellina proxima*, of which the valves are frequently united, and still show their dark epidermis.

This order characterizes the glacial beds throughout the whole of the Bute coast and the opposite shores of Cowal. The red brick-clay sometimes dwindles down to only a few inches in thickness, but it is almost always found between the shell-clay and the hard till. It retains throughout the same colour, the same impalpable unctuous texture, and fine lamination. Its freedom from stones is remarkable. Nowhere have I seen a single pebble in it. Mr. Macbride, who has been looking at it for years, has been equally unsuccessful, and the workmen at the Kilchattan tile-works assured me they had never seen a single stone in this lower or brick-clay. The absence of shells is not less singular; after not a little inquiry I have been unable to ascertain the discovery in it of a single organism. Moreover, it appears to be very persistent in at least all the more sheltered parts of the Clyde basin. A fine laminated clay intervenes between the shell-beds and the underlying boulder-clay at Paisley. Round the whole of the coasts of Bute and on the Cowal shores, the invariable layer of fine, stoneless, and unfossiliferous clay is intercalated between the shell-bearing bed and the coarse, stiff, stony boulder-clay. The persistency of character of this clay-bed, and its extension throughout the basin of the Clyde, probably point to a uniformity of physical conditions in that area. The deposit must have been laid down with extreme slowness and tranquillity, as is shown by its fine impalpable texture and minute lamination. It probably accumulated in a considerable depth of water, for it contains no interbedded layer of sand or gravel, such as might indicate a proximity to the shore. Yet it is found along high-water mark in localities where the ground rises with tolerable rapidity from the sea to a height of 800 feet and more. Even if it had been formed under a depth of 800 feet of water, its margin (now seen a little above high-water mark) could not have been more in some places than a few furlongs from the nearest shore. If this clay has resulted from the deposition of glacial mud, either borne from the land by coast-ice or washed off the

seaward ends of glaciers by the action of waves and currents, it is difficult to understand why it contains no stones; for stone-laden fragments of ice could hardly fail to be drifted from the shore. Fine mud carried out to sea by rivers would be free from stones, or the waves acting on banks of boulder-clay might transport a large amount of fine sediment to deeper water. I am not sure, however, that these two agencies are sufficient to account for the existence of this fine clay. One thing at least seems certain, during the accumulation of this fine laminated clay, there could hardly have been much stone-laden ice drifting about on the Firth of Clyde. Perhaps the truth may be that this great land-locked arm of the sea was frozen over during the greater part of the period represented by the laminated clay, and that the south-westerly gales, though they may have broken up the ice in the main channel of the Firth, were unable to dislodge that which crusted over the more sheltered inlets, such as the Kyles of Bute, where, protected from wave action and from drifting ice, fine glacial mud was deposited over the sea-bed by submarine currents. But the question still remains, why is this laminated clay destitute of fossils? It was eminently fitted for their preservation had they ever been embedded in it. We cannot doubt, therefore, that they never could have been there, otherwise their remains would have been preserved as perfectly as those in the shelly clay which lies immediately above.

The clay in which the shells occur indicates a change in the physical conditions of the Firth during the accumulation of these strata. It usually contains stones; sometimes it is full of them. This is well seen in Kames Bay where the stones, though usually small, are thickly interspersed through a fine dark-coloured sandy silt. Some of the larger stones, perhaps six or eight inches in length, have the greater part of their surface covered with the *Balanus Uddevallensis*, which attains in the clay of this bay a greater size than in any other part of the Clyde. It does not appear that any instances have occurred of *Balani* crusting the under surface of the stones. I searched long and carefully for a striated surface among these stones, but without success. They are both rounded and angular, resembling in this respect the ordinary rubbish of the beach,

where ledges of clay-slate are exposed to the waves and the weather. Yet it is remarkable, that notwithstanding this plentiful intermixture of stones, the clay is not commonly coarse and sandy. It never acquires the stiffness and the gritty earthy aspect of the boulder-clay. On the contrary, though sometimes mingled with sand and gravel, it retains on the whole the character of a fine silt. Nevertheless, the contrast between this clay and the laminated deposits on which it lies, is clear and abrupt. The shell-clay, as a rule, is not laminated; indeed it shows very scant traces of stratification. We pass at once from a fine fissile unfossiliferous clay (usually of a reddish tint along the Bute shores) up into a dark grey silt full of stones and shells.

There must thus have been a considerable revolution in the character of the agents which were carrying sediment across the bed of the Firth of Clyde during the accumulation of these strata. The gentle currents which carried the laminated clay were replaced by a more complex system of transportation. For it is evident that the currents, which were engaged in laying down the fine silt of the shell-bed, were wholly unable to move even the smallest pebble or stone which that stratum is now found to contain. Had the stones been borne to their present position by wave action, by ground swells, or by powerful submarine currents, it is inconceivable that they should be found lying in and wrapped round with fine silt. On the contrary, they would have been huddled together, and the silt would of necessity have been swept away. Besides, the condition in which the shells occur, at once disproves all violent action. They are in the most perfect preservation; their valves, seldom far apart, are frequently united, and often retain their epidermis even at the bottom of the bed, with numbers of stones around and above them. It seems undeniable, therefore, that some other agency must have been at work, quietly dropping stones, like those of the beach, upon the finer sediment that was gathering in still water. We shall, probably, not greatly err in ascribing no small share of this transportation to the action of coast-ice. Along the shores of Bute, as for instance in Kames Bay, the stones in the clay-bed are exactly such as a cake of ice forming on shore at the present

day would lift up and carry seawards. Moreover, the coast-line, which is rocky, consists of soft clay-slate with veins of quartz, and gives rise to the formation of shingle and mud, but of hardly any sand. If a piece of coast-ice, therefore, were now to form on the shores of Bute, it would bear away angular fragments of slate and rounded pebbles of grit and quartz, but would rarely have its bottom coated with sand. Hence, almost the only foreign ingredients which would be mingled with the silt of the deeper water, would be the various pebbles and boulders of the beach—a circumstance which harmonizes well with the fine texture of the clay-bed, notwithstanding the number of its imbedded stones.

But besides the action of coast-ice, we must also take into account the effect of the waves, beating upon exposed banks of boulder-clay, and causing the finer sediment to be transported seawards. There may, likewise, have been a considerable quantity of fine sediment carried away from glaciers either by rivers, or, if the glacier reached the sea-margin, by the waves. In this way we may conceive that the Firth was discoloured throughout a large part of its area, by the glacial mud brought down from the surrounding glens. Such a condition of things is well explained by many parts of the Arctic regions at the present day. Thus, the great glacier on the south-east coast of Spitzbergen runs for about thirty miles along the sea-margin in a line of precipice, rising from 20 to 100 feet out of the sea. “Much of the ice which floats away from these cliffs is heavily charged with clay and stones, and the sea for miles around is sometimes discoloured from the quantity of mud which is washed off this floating land-ice by the waves.”¹

If these suggestions appear reasonable, we may regard the stratified clays of the Clyde basin as having been formed during a gradually decreasing cold. At the beginning, the more land-locked inlets may have been permanently frozen over, and then the fine laminated clay gathered slowly under the ice over the surface of the submerged boulder-till. As the temperature increased, this frozen envelope would be more and more broken up in summer; much coast-ice would thus be driven about the bays and kyles, and to this period we may ascribe the produc-

¹ Lamont, *Quart. Jour. Geol. Soc.* vol. xvi. p. 429.

tion of the shell-clays. While these changes were in progress, the general level of the land appears to have been rising. The same upward movement continued for an infinitely protracted period, during which the climate ameliorated, and the more boreal and Arctic forms retired from our seas to more congenial habitats in the far north.

It is deserving of inquiry, whether or not the fine laminated clay underlies the shell-bed in the more exposed parts of the western coasts, and if it exists there, whether it contains transported stones. The only locality of this kind which I have had an opportunity of examining, is on the flat mossy land between Crinan and Lochgilphead. Through the valley now traversed by the Crinan Canal, the full swell of the Sound of Jura and the open Atlantic beyond must have rolled into Loch Fyne. The glacial shell-bearing clay occurs in this hollow, and was recently well exposed in a deep drain near Lochgilphead, elevated only a few feet above high-water mark. The laminated clay is there absent, as the subjoined section will show:—

1. Vegetable soil.
2. Ferruginous gravel two to three feet.
3. Pale lead-coloured sand two to three feet.
4. Pale grey clay is an irregular stratum filling up hollows in the surface of the underlying deposit. It is full of the usual northern shells. (*See Appendix.*) The *Mya truncata* is especially abundant, rows of them standing together with their siphonal ends upwards, and boring into the surface of the boulder-clay below. So perfectly are they preserved, that the siphon itself still remains in the clay.
5. Pale grey boulder-clay, full of scratched fragments of various grits and schists.

It may be observed also, that when the stratified clays abut against the sloping banks of boulder-clay which rise upward from beneath the sea, there is of course an actual juxtaposition of the shell-bearing beds and the boulder-clay.

To some of the geological questions suggested by the fossil contents of these clays, I shall return on a subsequent page.

Shell-bearing Clays of Aberdeenshire, etc.—The lower districts of Aberdeenshire,¹ bordering the sea, present a well-developed

¹ See Jamieson, *Quar. Jour. Geol. Soc.* vol. xiv. p. 509, from whose description the following account of the Aberdeenshire clays is compiled.

series of sands, gravels, silts, and clays, belonging to the marine or stratified Drift. This series attains a great thickness, sometimes exceeding one hundred feet. It ascends from beneath the present sea-level up to a height of at least 450 feet, but is chiefly developed in wide basin-shaped tracts on the lower grounds. Shells of an Arctic type have been found in it up to a height of 250 feet, thus linking it in true geological connexion with the clays of the Clyde.

In general aspect, it does not differ greatly from the character which the stratified Drift presents on the western coasts. It consists of alternations of fine clay and silt, with beds of sand and gravel. These are well shown in a section given by Mr. Jamieson, from the tile-work at Invernettie, to the north of Buchan Ness.

1. Blackish loamy earth,	1 foot.
2. Reddish brown clay, apparently devoid of stratification or lamination, and containing stones of various kinds, and of all sizes up to $4\frac{1}{2}$ feet in diameter, often striated and grooved on the surface,	30 to 40 feet.
3. Clay of a brick-red colour and finer nature, and apparently free from boulders,	1 „ 2 „
4. Very fine, laminated, dark-brownish clay, quite free from stones,	2 „ 4 „
5. Fine brownish grey sand, devoid of all stones or pebbles of any kind; the bottom of it has not been reached, but it has been penetrated to a depth of	20 „

The stony clay No. 2, presents several points of interest. Its boulders are of a heterogeneous kind, granites, schists, green-stones, sandstones, flints, etc. But they do not bear so large a proportion to the clay as to prevent the latter being used for brick-making after the stones are taken out. The largest block noticed by Mr. Jamieson, measured $4\frac{1}{2}$ feet long, $2\frac{1}{2}$ feet broad, and $1\frac{1}{2}$ thick. It was rough and angular on all sides but one, which was smoothed and striated in the direction of the longest diameter of the block. Many of the stones, however, are striated on all their sides. In the same stony clay this observer found traces of broken shells, occurring in films of coarse reddish sand in various parts of the deposit, and a broken fragment of a shell was picked out of the fine clay No. 4.

At another tile-work, three miles west from Peterhead, a fine

laminated clay is overlaid by a similar unstratified stony clay, in which blocks of three tons in weight are occasionally found. Boulders from two to three feet in diameter are frequently met with, and in a few instances the stones may be observed to be striated. This clay also contains shells, and when the stones are taken out is used for making bricks.

It will be apparent, from the description already given, that this clay differs essentially from the true boulder-clay or till. It is a fine brick-clay in which the stones are accidents, and its shells prove it to be a marine deposit. In short, it appears to have been deposited as fine silt at the bottom of a sea over which rafts of ice dropped the stones which they bore away from the adjacent land. The occasional striation of the boulders may have been produced either by coast-ice grating along the beach, or by glacier action, if the drifting ice came from the seaward extension of a glacier.

Along different parts of the eastern coast of Aberdeenshire, vast heaps of gravel and sand are found, apparently overlying the clays. They occur in mounds and long straggling ridges exactly like the kames already described. A good illustration is described by Mr. Jamieson, from the parishes of Slains and Cruden.¹ There, a range of gravel ridges, locally known as the Kippet Hills, runs with hardly any interruption in a zig-zag, tortuous, indefinite line for more than two miles. These ridges generally rise to the height of thirty or forty feet above their base; their sides are steep; their crest so narrow that two carts could barely pass each other on them; and their breadth is such that a stone could be easily thrown quite over them. They consist of sand, gravel, and water-worn pebbles, sometimes very coarse, and without any arrangement, sometimes finer, and passing into undulating sandy layers. Broken shells, such as the massive hinge of the *Cyprina Islandica*, occur both in the coarse and fine varieties.

In some localities the gravel ridges are dotted over with large erratics. This is conspicuously the case at the Menie Coast-Guard station, where boulders of trap, granite, and gneiss, some

¹ He is inclined to regard these mounds as older than the gravel which overlies the stratified beds at Aberdeen and elsewhere, and as perhaps contemporaneous with the stratified silts and clays which were laid down in deeper water.

of them six feet long, may be seen resting on the sides and summits of the mounds. In the same neighbourhood, the observer from whose description I quote, met with one gigantic boulder of granite measuring fifty-four feet in circumference, and rising about seven feet above ground. Another had a circumference of seventy-eight feet, and a height of six feet. These blocks are either rounded or rugged, with few sharp angles. No striations appear to have been observed upon them. But some miles farther to the north, at Cruden, a similar series of large blocks is scattered over the ground. These have been observed to be, in some cases, worn and striated on one side, which, it appears, is always the lower surface or bed of the stone.

The mounds of gravel are not only dotted over with large erratics (which are said also to occur occasionally in the interior of the ridges), but their surface is often obscured by a coating of red clay. This deposit is never of great thickness, and is generally absent from the higher mounds, or forms but a thin layer over them. In at least one example, near Menie, it has been observed encircling the base of a large block which lay immediately upon the gravel. In this case the sequence of events is very interesting. First, a series of mounds of shingle was thrown up probably along a coast-line, but during a time when the climate was so severe that masses of ice, charged with boulders, drifted over the sea. The stones thus transported, often of great size, were stranded upon the banks of shingle; and then it would seem that the sea-bottom was depressed to a lower level beyond the influence of the shingle-beating tides; that there it received a coating of red clay, which filled up inequalities of the old sand-banks and gravel mounds; and that finally the whole was re-elevated, and left beyond the reach of the sea.

The same series of stratified beds of sand and clay is found skirting the shore round into the Moray Firth. They have been long known at Gamrie, where Mr. Prestwich described them¹ as attaining in places a thickness of 250 feet, and rising 350 feet above the sea. Mr. Robert Chambers has likewise visited them, and published a section wherein numerous alterna-

¹ *Proc. Geol. Soc.* ii. 546.

tions of sand and clay, containing *Astarte arctica*, *Natica clausa*, *Tellina proxima*, etc., rest upon a fundamental deposit of boulder-clay.¹ Some of the excursions that marked the closing years of the life of Hugh Miller were directed to this and some other localities for glacial shells; and in his collection he had a considerable number of well-preserved Arctic shells from the Gamrie beds.

These deposits run far up the valley of the Deveron and its tributaries. They occur, for instance, at Huntly, where Mr. Jamieson found them at a height of 360 feet above the sea-level. Up the course of the Spey they extend in terraces, which, at Rothies, rise nearly 400 feet above high-water mark in the Moray Firth.

Although the occurrence of the marine Drift has not, so far as I am aware, been recorded from the upper reaches of the Moray Firth, nor from the eastern coasts of Ross and Sutherland, there can be little doubt that it exists there. On the Caithness coast in the neighbourhood of Wick, occurs that curious unstratified fossiliferous clay which has been already described as probably coeval with the boulder-clay of other parts of Scotland. In the character of its fossils it resembles the ordinary stratified Drift. Mr. Peach has found it to contain forty species of various marine organisms. Those belonging to the mollusca are thirty-two in number, of which twenty-nine are species now living in the British seas, two Scandinavian, and one Arctic.² The height at which these remains are found in Caithness varies from 60 to 200 feet above the sea.

On the eastern coast from Aberdeen southward, shell-bearing clays of the Drift have hitherto been scarcely ever seen. Professor Fleming found some Arctic shells in a clay at Tyrie, near Kinghorn in Fife,³ and true Arctic forms have recently been obtained by the Rev. Thomas Brown, from near Elie. At Dunbar, also, a number of beautifully preserved *Ophiuridæ* have lately been disinterred at the brick-works, but without any shells. This paucity of shell-beds in the Drift on the

¹ *Proc. Roy. Soc. Edin.* vol. iii. p. 332.

² *Brit. Assoc. Reports*, for 1862.

³ *Lithology of Edinburgh*, p. 77. He found *Leda truncata*, a shell not now living in our seas, but still extant in those of the Arctic regions.

east coast may, however, be, to a large extent, due to insufficient observation.

Down the western coast of Scotland, although some of the fossil glacial shells are occasionally dredged in deep water, the shell-bearing clays of the Drift series appear to be but scantily developed until we reach the quiet sea-lochs of the Clyde. The Rev. Mr. Macbride informs me that this summer he found *Tellina proxima*, and other characteristic shells, in a clay on the coast at Oban. Mr. Jeffreys has also this year described a deposit containing similar shells near Fort-William. According to his observations, an elevated sea-bed, whose organic contents indicate a moderate depth of water, is there surmounted by a beach deposit containing littoral species. Nearly all the shells found here live in the adjacent seas, but a few of them now exist only in more northern latitudes.¹ Mr. T. F. Jamieson informs me that he has obtained *Natica clausa* and *Pecten Islandicus* from the raised beach, which corresponds to the forty-foot terrace of the west of Scotland. If these species were not washed out of the older sea-bottom on which the raised beach deposits rest, their occurrence would indicate that the forty-foot terrace belongs to a part of the Drift period.

In the neighbourhood of localities where no shell-clays have been noticed, the operations of the dredge sometimes show that these deposits probably exist. Hence, it seems evident that the existing bed of the Atlantic, from the Shetlands south by Skye and the Hebrides to the Clyde, is still covered with the silt and shells of the glacial period. Single valves of shells, not known as living denizens of our seas, have been dredged up, sometimes in so fresh a state as almost to lead to the belief that the species can hardly be wholly extinct. Yet other valves, evidently of fossil specimens, are met with, and naturalists are therefore in the habit of regarding the shells as having come out of a deposit of the Drift series which forms the bed of the sea.

In this way we are led to perceive that it is only a part of the deposits of the glacial period which now appears on the land. What was the sea bottom then, remains to a large extent the sea bottom still. The changes in organic life which

¹ *Brit. Assoc. Reports*, 1862.

have taken place in the interval have gone on over the same area, species after species gradually dying out, and others taking their place round our coasts. Nay, the process of change must be going on slowly and imperceptibly still.

It is the province of the naturalist rather than the geologist to investigate the organic remains of these deposits, and to speculate from their peculiarities and mode of occurrence what may have been the nature of the climate, the depth of the sea, and the probable character of other physical conditions under which the organisms lived and died. Mr. Smith, of Jordanhill, has led the way into this fascinating field of research. But much remains to be explored. The minute history of the life of the period has still to be written, and doubtless many a deeply interesting page has yet to be added to the story of the glacial Drift.

Into the zoological problems suggested by the fauna of the marine Drift, however, I do not enter. Some of them have been discussed by Edward Forbes in his memorable paper on "The geological relations of the existing Fauna and Flora of the British Isles." And the subject is at present engaging the attention of others, who will, I trust, ere long, publish the results of their researches. In the meantime, the reader who is not familiar with the generalizations of Edward Forbes, must master them if he would acquire a philosophic view of the relation of the plants and animals of the Drift period to those inhabiting our islands at the present day.

In now drawing attention, however, to some general conclusions which the stratified Drift of Scotland appears to warrant, I may refer in a few words to the bearing of those fossils upon some of the geological questions which have engaged our attention in this Memoir.

Inferences deducible from the character of the stratified Drift.

In the foregoing pages reference has occasionally been made to the probable circumstances under which different parts of the marine sands and silts of the Drift series were accumulated. It may be useful to present here a general summary of the inferences which these deposits naturally suggest.

1. In the first place, when the stratified Drift was in the process of formation, the British Islands previously submerged probably 2000 feet below their present level, were rising above the sea. This upward movement was perhaps more continuous in its earlier stages, while towards its close, though the rate of rise may have been the same or even more rapid, it was interrupted by long pauses when the land remained stationary, and when in consequence lines of sea-cliff were eaten away, and terraces of littoral deposits were thrown down. After making every reasonable allowance for the wasting influences of nature, working through an indefinitely protracted period, we can hardly suppose that if the ascent during all save its closing scenes was extremely slow, and was marked by long pauses when the sea stood for centuries at certain levels, there would not have been more unequivocal traces of old cliff lines and raised beaches in the interior and upper parts of the country. It is undeniable that the nearer the lines of raised beach approach to the present sea-margin, they must remain fresher and more distinct, and that the higher they rise above that level, and the longer therefore they have been exposed to the rains and frosts, the less distinct will be their traces. It may be doubted, however, whether this is enough to account for the general absence of indubitable beach-lines over the greater part of the interior of the island. It is perhaps as likely that the rise of the land, even though progressing by intervals, with occasional interruptions of a retrograde kind, was yet on the whole so rapid as not to permit of the erosion of sea-cliffs and the accumulation of well-marked littoral terraces.

But whether we hold that the movement was infinitely slow and continuous, or advanced in successive stages with long pauses between, or was accomplished by a series of quick upheavals or jerks, we must admit that while it was in progress, the mounds of sand and gravel, the huge erratic blocks, and the sheets of clay and silt which form the stratified Drift were accumulated. In the higher parts of the island, as we have seen, the evidence of the submergence is chiefly furnished by mounds of water-rolled gravel and sand, and by the dispersion of erratic blocks. These materials may in some instances have been deposited by rivers flooded by rapid thawings of the ice

and snow of the uplands. Yet in other cases, even though they are associated with no marine organisms, they are seen to lie in places far out of reach of any stream, and on which only the waters of the ocean could have rolled. Beds of clay of marine origin are chiefly found at lower levels, especially close to the shore, whence they descend beneath the sea. It is in these clays, and more rarely in the mounds of sand and gravel which overlie them, that the organic remains of the stratified Drift occur. The sandy and gravelly nature of most of the Drift in the interior of the country, with the abundance of stratified clays in the tracts bordering the sea, is capable of several explanations. We may conceive the upheaval of the land to have been for the most part so gradual, that each successive deep-water deposit, as it came up to the level of the breakers, would be washed away, and littoral sand and shingle would be left in its place, while during the later stages of the elevation there were long periods of rest, between which the rate of rise was sufficiently rapid to allow large areas of the submarine silts to be upheaved beyond the reach of the waves. Or with perhaps less probability we may suppose that the clays were never formed save where we see them now, that is, in the extreme depths of the glacial sea, and that it was only towards the close of the long elevatory process that they were brought up to the light of day.

2. When these deposits were in the course of formation, the climate was so severe that both coast-ice and icebergs existed in abundance. This is shown by the scratched stones, by the large angular erratic blocks, and by the crumpled and contorted appearance of the sands and clays. Such proofs of a low temperature are not confined to any one part of the series of strata; they continue in some form or other from the highest point to which these beds have been traced, down to below the present sea-level. Glaciers too, as will be shown in the next section of this paper, existed in most of the higher districts of the country, and even pushed out their icy masses to sea. Hence the cold must have continued during the period of upheaval, gradually lessening as the land rose. The temperature of our area is still far from having regained the warmth which characterized it in the ages immediately preceding the commencement of that long

process of refrigeration which culminated in the glacial period. Hence it may still be growing insensibly more genial.

3. The nature and grouping of the beds composing the stratified Drift, afford on the whole evidence of regularity and tranquillity of deposition; they lend no support to theories of vast "waves of translation." It is possible that some of the phenomena of the kames above described, may be to some extent explained by the supposition of quick upheavals, or rather jerks of the land, whereby the sea was driven back with violence. But these are exceptional instances. The perfect stratification, current-bedding, and fine lamination almost everywhere visible, point to modes of accumulation such as are still going on in the seas around us.

If we pass to the consideration of the organic contents of these strata, we meet with similar evidence of quiet and peaceable agencies. The shells, in the great majority of cases, especially on the west coast, are not drifted specimens. This is shown by their perfect preservation, even the tender *Tellina proxima* retaining both its valves with their epidermis. The *Mya* is found boring in the clay with its siphuncular end uppermost, just as it died. The fragile *Balanus* may be seen thickly crusting the upper surface of a stone; had it been knocked about even for a short distance, it would have been detached from the stone, and have fallen to pieces. The same cirrhipede may be found in groups on the valve of a *Pecten Islandicus*, nay, I have seen it even on a specimen of that shell which had the two valves together, showing that the mollusc had lived and grown to a considerable size, with a heavy barnacle firmly attached to it. Indeed, the evidence which the shells afford of the tranquil character of the sea in which they lived, is of the fullest and most interesting kind.

It is true, that in certain localities the shells are frequently broken. In some of the clays along the Aberdeenshire coast, for instance, only fragmentary shells occur, and at Wick the same fact has long been noticed. From this circumstance, Edward Forbes inferred that icebergs or great waves of translation coming from the north, broke upon the northern shores of the British Islands, and gave rise to disturbed and unstratified deposits containing only broken shells, while in the quieter

firths and creeks of the Clyde basin, protected by the Argyre-shire mountains, the usual marine deposits went on without interruption, and the organisms of the sea-bed were buried in the places where they died.¹ This explanation may account in part for any difference which exists between the state of the shells in the sheltered parts of the Clyde and those in the more exposed coasts of Aberdeen and Caithness. But there is good evidence of a quiet sea-bottom during the glacial times, even on the shores of the north-eastern counties. The fine lamination of the clays there has assuredly not been produced or interrupted by "waves of translation." These deposits must have accumulated tranquilly on the sea-floor, over which icebergs and rafts of coast-ice, driven about by winds and waves, dropped their burdens of mud and boulders. It does not seem necessary to suppose the sea in any degree more buffeted by storms or stirred by earthquake waves than it is to-day, in order to account satisfactorily for the phenomena of the marine Drift, even on the northern coast of Scotland.

4. If during the period represented by the stratified Drift, the climate was of such severity as to cause the freezing of the surface of the sea, and to give rise to masses of drifting ice, it is natural to expect that some trace of this rigorous temperature should be seen in the remains of the organisms by which at that time the sea was tenanted. And this is found to be the case. I have already remarked that Mr. Smith, of Jordanhill, was the first to point out to geologists this interesting proof of a former severe climate in the British area. Since his observations were made, investigations have been carried on in many parts of these islands, as well as on the continent and in the far north. The result has been amply to confirm and extend Mr. Smith's conclusions.

It is now known that the fauna of the marine Drift is eminently of a northern character, indicating a temperature somewhat like that of the waters which wash the coasts of Greenland or of Labrador. Though the great majority of the shells found in these beds of clay and silt are also living in our seas, a small number are as yet unknown in the living British fauna. These were at first pronounced to be extinct species, but they

¹ *Mem. Geol. Survey*, vol. i. p. 384.

have almost all been since found alive in more northern latitudes. Such are *Mya Uddevallensis*, *Tellina proxima*, *Saxicava sulcata*, *Pecten Islandicus*, *Trophon scalariforme*, *Natica clausa*, etc. Other shells, though common in the Drift, now linger only in the deeper abysses of our seas, where, driven from all the higher zones of the sea in which they once abounded, they appear to be slowly dying out. Yet they still live in abundance in the boreal and Arctic seas. Examples are furnished by *Panopœa Norvegica*, *Puncturella Noachina*, *Nucula tenuis*, *Trophon clathratum*, *Natica pusilla*, *Trichotropis borealis*, etc. Moreover, those northern forms, which are still found in the profounder depths of the seas round the northern parts of the British Islands, are small and rare when compared with those of the same species which occur in the clay-beds. This is well shown by *Panopœa Norvegica*, which, though a very variable shell in the clay-beds of the Clyde basin, often occurs greatly thicker and stronger than any living example yet found in British waters. The fossils in this respect approach much closer to recent specimens from the Arctic seas than to those that have been dredged round our coasts. Sars has remarked the same difference between the fossils of the Drift in the south of Norway, and living specimens of the same species in the adjacent seas. He instances *Natica clausa* which, instead of occurring as a fossil in the rare and dwarfed state in which as a recent form it comes south to Bergen, is as large as the living individuals from Finmark and Greenland.¹

A hardly less striking proof of the ancient rigour of the climate in this country is furnished by a comparison of those species which are still common round the coasts of Britain, and fossil specimens of the same species from the clay-beds. The latter are often greatly thicker and more massive than their living representatives, and this increase of thickness and size is sometimes (as in *Saxicava sulcata* and *Mya truncata*) carried to such an extreme, that at first sight we can hardly recognise the fossils as identical with the same familiar species of our present seas. Other instances are furnished by *Ostrea edulis*, *Pecten maximus*, *Cyprina Islandica*, *Modiola modiolus*, etc.

¹ *Jagttagelser over den Glaciale Formation; Universitetsprogram* (Christiania), 1860, p. 57.

5. The Crag deposits of the south-east of England unequivocally prove that the severe temperature of the glacial period did not come on suddenly, but that on the contrary, during a long course of ages, the climate gradually changed from one of a warmer character than we at present enjoy, to the intense cold of which the evidence is furnished by the phenomena of the glacial Drift. It is reasonable, therefore, to infer that as the cold increased by slow degrees, so by slow degrees it diminished. That this inference is probably correct is shown by the character of the stratified Drift of Scotland, as contrasted with that of the old boulder-clay. When the land rose again after the submergence, it was no longer wholly ice-covered; yet in its higher valleys it had numerous glaciers which protruded into the sea, while sheets of ice still formed along the coast-line. But though it may eventually be possible to show that the higher zones of the marine Drift indicate a severer temperature than the lower ones, and that the space between them contains evidence of a gradual amelioration of climate, such proofs have not yet been adduced.

When we examine a series of shell-bearing clays in any of the maritime districts, one of the first suggestions which present themselves is to determine the relation of these deposits to such recent marine strata as may be seen to overlie them. In such a succession of fossiliferous beds, can we trace any gradual change in the character or numerical proportions of the organic remains, indicating a corresponding change in temperature, depth, or other physical conditions of the ancient ocean in which the animals lived? So far as I am aware, no such gradation has been observed. Along the margin of the great basin of the Clyde, the old bed of the glacial sea, charged with its characteristic shells, still serves in part at least as the floor of the present sea, and where it slopes inland from the shore, it is found to be abruptly covered by the sands and gravels of the newest raised beaches, wherein all the shells are of species still inhabiting the Firth. In this district, therefore, there is no connecting link between the deposits of the glacial and those of the recent period.

The sharpness of this line of demarcation affords, however, no ground for the supposition that it indicates a corresponding

suddenness of transition from the fauna or from the temperature of the ancient epoch to those of the modern one. It has been supposed, for instance, that the bed of the glacial sea must have been suddenly elevated into land, that the characteristic boreal and Arctic shells were thus exterminated from our area, and that the ground afterwards subsided to receive the deposits of the present ocean. This reasoning proceeds on the assumption that the geological records which we possess are a complete compendium of the physical revolutions of the globe. Yet a more thoughtful survey of the glacial deposits in their relation to the lines of raised beach, to the trend of marine currents and wave-action, and also to the distribution of the present organisms of our seas, will probably convince the observer that the evidence is all in favour of a gradual transition from the climate and fauna of the glacial period to those of the present day. The hiatus between the deposits of the two eras will afford him only another proof of the fragmentary character of the annals from which geological history must be compiled; nor will he fail to perceive that if in a group of strata deposited upon each other in regular and apparently unbroken sequence, and so recent as almost to belong in a manner to his own times, so immense a gap can exist, he may well concede the possibility of an infinite number of breaks in the succession even of what may appear to be the most closely consecutive geological formations. The unrecorded ages of the geological past, from Cambrian times up until now, may thus vastly outnumber those of which a meagre and imperfect chronicle is preserved in the stratified crust of the earth.

The mere absence of intermediate strata between the glacial clays and the sands and gravels of the recent raised beaches is no proof that such strata never existed. On the contrary, if we reflect on the nature and origin of the raised beaches, we shall perceive that the chances of the preservation of any parts of such connecting strata must have been infinitely small. The twenty-five-foot terrace, resting as it does against a line of ancient sea-cliff, indicates that the land in its upward progress stood at this level for an incalculable number of ages. During this vast interval, the sea was beating upon the upraised parts

of its former bed, in which the records of its inhabitants and their changes were preserved. It does not require a moment's reflection to see that the soft clays and silts could not fail to be washed away. Hence, not only such deposits as were formed after the close of the glacial period, and may have contained the organic evidence of the gradual amelioration of climate, but even large portions of the underlying glacial clays may have been entirely effaced. And in harmony with this probability, we find that the raised beach sometimes rests upon beds of clay overlying the glacial shell-bed; sometimes on that shell-bed, sometimes on the underlying, finely-laminated clay, sometimes on the old till, while in other and more exposed localities, the whole of the Drift-beds have been swept away, and the raised beach rests on the solid rock. The same process of varying demolition can be admirably traced at present in progress along different portions of the Firth of Clyde. Thus, in Etterick Bay, on the west side of Bute, the westerly waves have entirely washed off the upper clay from the beach; the shell-clay is only visible here and there, under gravel and boulders; the laminated clay and the underlying till are likewise undergoing the same process; while in some places the whole of these clays have been removed, and the hard slates protrude upon the beach among the sand and gravel now thrown up by the tides. If a certain part of this coast-line were to be elevated, an observer might say that the period of the boulder-clay was followed immediately by that of the raised beach. If another portion were upheaved, he would find that between the boulder-clay and the raised beach there was an intermediate period, represented by the laminated clay. The examination of a third spot would show him that he required to intercalate another long interval, indicated by the shell-beds; while a fourth survey might reveal the existence of the clays overlying the shell-beds. After such repeated lessons he could not fail to learn that there might still be other missing portions of the series which he could not supply—portions perhaps as numerous and important as those which he had succeeded in discovering. In like manner, though no connecting links may be traced between the deposits of the glacial sea and the post-glacial raised beaches, we shall probably greatly err if we

dispute their former existence, and seek by any sudden upheaval to account for the sharp line of demarcation between the strata of the two periods.

If we could examine the present bed of the Firth of Clyde, we should probably find there the missing part of the record. The glacial clays would be found covered by others of recent date, and the gradual changes from a more northern fauna to the present temperate one, would in all likelihood be indicated by a suite of well-preserved shells.

That the amelioration of climate and the change of marine life proceeded by a very slow gradation, is indicated by the present distribution of the mollusca of the British seas. It is now upwards of sixteen years since Edward Forbes described the existence of isolated groups of northern shells in some of the deeper abysses off the west coast of Scotland.¹ Such "boreal outliers" usually lie in a submarine hole or valley from 80 to beyond 100 fathoms in depth. "Their inhabitants," he says, "are decidedly of more northern character than the members of the Celtic fauna, and the species are such as are assembled together far to the north on the coast of Norway." An illustration of these features is afforded by the deeps of Loch Fyne, which were dredged by Forbes, with Mr. MacAndrew, in 1845. "The dredge," says the former naturalist, "brought up eight species of testaceous mollusca, one crustacean, and two echinoderms. Of these mollusca, five species were alive. One, a minute species of *Rissoa*, was new; the remaining four were *Nucula nuclea* (a northern variety), *Nucula tenuis*, *Leda minuta*, and *Lima subauriculata*. Of these, the number of examples of *Nucula tenuis* and *Leda minuta* exceeded greatly those of their companions; they are both essentially northern and Arctic forms, ranging from Greenland to the Scottish seas, and not known south of Britain. The *Nucula nuclea* and the *Lima* range from Greenland to the Mediterranean; but the variety of the former taken is confined to northern seas, and the latter is very rare, and only found at great depth in seas south of Britain. The dead molluscs taken were *Abra Boysii*, a species of similar range with *Nucula nuclea*; *Cardium Löweni*, a Scandinavian species, and *Pecten Danicus*, a Norwegian species,

¹ *Mem. Geol. Survey*, 1846, vol. i. p. 387.

found only, in the British seas, in the lochs of the Clyde, and there rarely alive, though dead valves are abundant, *as if the species thus isolated were now dying out*. The echinoderms were *Ophiocoma filiformis* and *Bryssus lyrifer*; the former a Norwegian species, the latter ranging to the Arctic seas, but southwards not known beyond the Clyde region. The crustacean was new, both as to genus and species. "It will be observed," he adds, "that the *assemblage* of animals thus taken at this great depth was essentially Arctic."¹

The explanation proposed by the same naturalist to account for this isolation of northern forms in the deeper abysses of our seas was one of his most beautiful generalizations. He supposed the bed of the glacial sea to have been partially upheaved. This upheaval, by altering the level of all the still submerged portions, would produce marked effects upon the fauna of the different submarine zones. A number of the forms whose organization might be too delicate to endure the change of conditions, would be destroyed over the area of elevation, while another group, consisting of such species as had greater capacities for vertical range would survive. By this process, and while, owing to other and more general causes, the climate of this part of the globe became more genial, the more thoroughly boreal and Arctic forms which had lived in the upper zones of our seas during the Drift period, would be locally extirpated, and would be driven farther and farther north into more congenial temperatures. In the profounder deeps round our coasts, however, where the conditions of temperature would still remain suitable, northern forms would continue for a time to maintain their ground. The extreme scarcity of some of these northern mollusca in a living state in such abysses as those of Loch Fyne, and the comparative abundance of dead valves, seem to show, as Forbes suggested, that such species are slowly dying out. They have been able to maintain an unequal contest against the altered conditions of their places of abode, and we now see them in the last stages of their history as living British species.

These, and similar considerations arising out of a comparison of the distribution of the fauna now inhabiting the British seas, with the fauna which lived in them during the glacial epoch,

¹ *Op. cit.* p. 389.

afford a strong presumption, that the organic changes which have intervened between the two periods, have not been the result of any sudden catastrophe, but that on the contrary they have arisen gradually out of a complication of physical causes, and that they are even now in progress still. The history of our own country is thus a not uninteresting commentary on the larger history of the globe. We see, that here the existing period does not stand severed by any arbitrary line from those which preceded it, but that with these it is bound up by innumerable interlacing ties. We see too that it is a period of never-ending progression, carrying on, slowly and imperceptibly perhaps, yet not less certainly, those vast cycles of change which have been handed down from the past, and shall be transmitted as an ever-increasing legacy to the future.

III.—LOCAL GLACIERS.—FINAL DISAPPEARANCE OF THE ICE.

The continuance of a severe climate, when this country was undergoing its last great elevation, is well shown by the stratified Drift, of which the details have just been considered. The same fact is still further proved by the remains of true glacier moraines. To the evidence which the latter present we shall now turn.

If the whole of Scotland was submerged at the time of the greatest depression, it might be possible, even in the most elevated districts, to draw a line between the results of the old general glaciation which preceded the submergence, and that later localized glaciation which is now to be described. But in the absence of any certain proof that the whole country was under water, we are left to infer that, in the upland tracts, at a higher level than say 2000 feet above the sea, the great ice sheet, which covered all the mountains and descended upon the lower grounds in the early part of the Drift Period, never disappeared until it was gradually dissipated by the amelioration of the climate. Hence the rock-dressings produced in these high-lying districts by the old ice-flow probably merge, without any intervening traces of sea-action, into those effected by the later glaciers. But in lower parts of the country there