August 15/74

J. Campbell

a Gift from the Author

Read on board the Dove

on the Nile near Mulatieh.

January 29. 1878.—

A very good paper but

I am not sure that I agree

See paper on the Intended

Canals of Glenroy sent to

the Author

Jamieson

[*From the* Quarterly Journal *of the* Geological Society *for August* 1874.]

On the Last Stage *of the* Glacial Period *in* North Britain.

By T. F. Jamieson, Esq., F.G.S.

Contents.

§ 1. *Introductory.*

In Scotland we seem to have at least three well-defined stages in the history of the Glacial period, viz. :—1st, the great early glaciation by land ice; 2nd, the period represented by the glacial marine beds, containing remains of arctic mollusca, when much of the country was covered by the sea; and, 3rd, what I shall call the time of the later glaciers. It is to the history of this last part that the following pages are chiefly devoted.

During the first stage glacial conditions seem to have attained their maximum, and the whole of Scotland appears to have been covered for a long time with snow and thick ice, as North Greenland is at the present day. An opinion has occasionally been expressed that it was the polar ice which at this time spread in a continuous mass from the arctic circle over a considerable part of the northern hemisphere, covering much of the north of Europe as well as most of Britain. I cannot say that I have met with evidence of a mass of glacier-ice from the polar regions having moved over the district with which I am acquainted. On the contrary, there are facts which seem to me inconsistent with such a notion. One of these is the occurrence of extensive beds of chalk-flints along the crest of a range of low hills running for six or seven miles inland from Peterhead.

These beds of loose flint pebbles, lying, as they do, on the very top of a range of bare exposed hills at altitudes of from 250 to 370 feet, must have inevitably been swept off by a great mass of glacier-ice moving over them from any quarter. It is true they have been carried away here and there, and cut off abruptly in certain directions, as if by the glacier-ice of the adjoining district; but for a distance of several miles they lie thickly along the very top of the ridge. Their quantity, and the extent of ground they cover, forbid us from supposing that they have been drifted from some foreign region; but assuming that they are native to the locality, it may still be said that they were not in the state of loose pebbles at the time of the ice, but may have been imbedded in strata of solid chalk, which have since been dissolved. This, however, I consider a very improbable supposition.

This ridge, although it attains the altitude of only a few hundred feet, is, nevertheless, higher than any ground immediately to the

north of it; in fact it may be said to be nearly open sea between it and the North Pole.

Ever since I visited the district of Lochaber and the Parallel Roads of Glenroy in 1861–62 I have inclined to the belief that there must have been a great development of snow and ice in this country after the submergence, or second stage of the Glacial period; and an examination of the glens around Ben Nevis impressed me at that time with the belief that the glacier, and *not* the sea, was the last occupant of the surface. It also seemed to me that the recurrence of severe glacial conditions on the land after it emerged would explain many facts otherwise very difficult to account for. In subsequently examining various parts of Scotland I have kept this point specially in view; and the result has been to force upon me the conviction that the development of snow and ice during this third stage of the Glacial period must have been far greater than most geologists suppose.

§ 2. *General Features of the Surface.*

The general features of the country, even in the lower districts, do not appear to me to correspond with the notion that since the sea retired nothing but the ordinary action of the elements has modified the surface. In such a case I should expect to find level sheets of gravel, sand, and silt, containing some remains of marine fossils in a more or less perfect state; also zones of beach-pebbles mixed with some littoral shells, and deposits of a similar nature capping eminences that had been in shoal water; and, in particular, I should look for traces of estuary mud along the curves of the wider valleys, where the tide and the river had formerly met. Now in Scotland, so far as I am aware, we have absolutely no trace of any such estuary beds containing remains of animals peculiar to places of the sort, except at levels below thirty feet, and which belong, as I have elsewhere shown, to a more recent period, when glacial conditions had passed away, the shells indicating a climate rather warmer than at present. How could the glacial sea have gradually retired, or, rather, how could the land have gradually emerged, without some tidal sediment being left here and there along the valleys where a pause in the change of level took place? It is true some have thought they have discovered traces of ancient sea-margins in certain more or less horizontal banks and terraces, which, however, admit of a different explanation; but no one, so far as I remember, has been able to point out any estuary beds, containing estuary fossils, along the valleys at high levels. Why, also, should we not see some more distinct lines of old sea-cliff and sea-caves at higher altitudes, and likewise some heavy masses of blown sand and shells, like what we find on the coast at present? The beds of glacial marine clay and sand have been destroyed along the valleys to an extent inexplicable on the supposition that the sea gradually retired and nothing but ordinary subaerial action followed. In certain low districts, where this clay has nearly all disappeared, patches of it are left on eminences and places just where we might suppose it

most likely to have escaped the action of glaciers; and at the mouth of some valleys (as, for example, that of the Dee at Aberdeen) we find masses of it which seem to be the denuded remains of beds that some powerful agency has swept clean out of all the rest of the valley. And some of these beds appear to have been dislodged from their original position and thrust out seawards in a confused mass, as in the banks near the Aberdeen lighthouse and powder-magazine —a result such as we might suppose would follow from a glacier moving down the valley over the beds of clay and sand, wasting them gradually beneath it, and forcing them partly before it.

Now let us consider what would be the effect of a glacier extending itself over beds of sand and clay such as had been deposited during the submergence of the country. The advance of the ice over this old sea-bottom would either destroy the marine beds, by pushing them before it and wasting them beneath it (the water flowing from the end of the glacier contributing to the effect), or it would move over them without entirely destroying them. Much would depend upon the weight of ice, its duration, the slope of the country, and also the depth and firmness of the marine strata.

Where the glacier was thick and the valley narrow and steep, the marine beds would probably be entirely cleared out. The glacier would push them bodily before it; and where it did slide over them, the pressure of the ice would work up the clay and sand into a liquid mud, which would be continually carried off by the water escaping from beneath the ice; so that the wasting of the mass would go on rapidly, and result in its entire destruction, leaving only the stones and washed gravel in front of the glacier. But where the glacier was not very thick, and the marine strata of considerable depth and firmness, I imagine the ice might slide over such a deposit without entirely destroying it. The effect would probably be to compress and wrinkle it to some degree, and to work the upper portion of it into an unstratified paste or mud mixed with stones. This would result from the grinding pressure of the ice and the want of good drainage for the water beneath it; for unless there was a current of water to carry off the mud, the material would remain beneath the glacier, although a part would no doubt be continually carried forward by adhering to its sole and travelling on along with it. The pressure of the ice pushing into beds of stratified clay and sand would, in some cases, displace them, and wrinkle them into folds, thus giving rise to beds of contorted drift.

The unstratified, unfossiliferous mass of pebbly clay which occupies so much of the surface, and is occasionally seen overlying marine beds containing arctic shells, may have been formed in the way above described. It occurs in many parts of Scotland, and has got the name of upper drift or upper boulder-clay. Much of what has been occasionally described as the upper covering of gravel and boulders I believe to be also a result of the action of the later glaciers. When these upper beds consist of marine deposits ground into mud by the action of the ice, it is evident that bits of broken shells may occasionally be found in them.

Mr. Trimmer, who devoted much attention to the superficial accumulations of England, and sought to explain them chiefly by the action of the sea and floating ice, was yet unable to overlook the remarkable fact that there is a general absence of marine remains, and of regular beds of these remains, in what he termed the Upper Erratics, not only in Norfolk, which he had specially studied, but also in every district of England, Wales, and Ireland he had examined *.

§ 3. *Disappearance of the Marine Beds.*

The general disappearance of the glacial marine beds over most of Scotland is a fact difficult to explain, except upon the supposition that there was a subsequent occupation of the ground by glaciers. The amount of submergence is on this account very difficult to determine; for the evidence of the sea's presence has been destroyed. Several geologists, influenced no doubt by the discoveries in Wales, have supposed, and perhaps rightly, that the submergence reached to a great amount, and that the former coast-line must at one time have been 2000 feet above the present, or even more. But when we ask for proof we get little that is satisfactory, the presence of far-travelled boulders at great heights being almost the only fact of any value; and this may admit of explanation by the agency of land-ice. Supposing, however, that the submergence was much less, and reached no higher than say 500 feet (which no one, I imagine, will consider an overestimate), we ought to find marine beds far more widely spread than we do. For with the exception of some of the flatter ground along the east coast, away from the mountains, and here and there over the Scottish coal-field, beds containing marine arctic fossils are unknown. As a rule, they are absent from all the Highland valleys, even at low levels, and, generally speaking, are not to be met with near hills, and from the country to the west of the Caledonian canal have not been reported at all.

In the Clyde district many shell-beds are known, but generally near the shore, and very little above the present reach of the tide. If we suppose that the glaciers again occupied the surface after the sea withdrew, it will afford a better explanation of the disappearance of the marine beds than any other I can think of. For much of Ireland and England the same hypothesis seems to be required.

In Caithness the area occupied by the dark grey drift containing marine shells probably marks the extent of ground in that quarter which escaped the action of the later glaciers. This area seems to be bounded by the hilly ground which borders the plain of Caithness to the west and south. In the latter direction it stops at the low ridge that divides the water of Dunbeath from Berriedale Glen, into which the grey shelly drift does not enter. Very likely the grey drift may have been cleared out of the lower part of Berriedale by a glacier; for some patches of it occur about the mouth of the

* Quart. Journ. Geol. Soc. vol. vii. p. 24, 1850.

glen, in the cliffs facing the sea. I regret having been prevented from tracing the outline of this peculiar fossiliferous drift of Caithness along all its western boundary; for features of interest will no doubt present themselves where the ice from the hilly ground came down upon it.

From Berriedale to Inverness, all along the eastern border of Sutherland and Ross, the later glaciers seem everywhere to have come down in great force to the present coast-line. At Ardersier, near Fort George, I came upon a small patch, a few yards in extent, of grey clay, containing arctic sea-shells. It was buried underneath, or enveloped in, a brownish unfossiliferous mass of gravel and silt, and seemed to be a remnant of some bed that had been destroyed by the action of the later glaciers. Its occurrence, however, interested me much, by showing that glacial marine deposits had once existed in that neighbourhood. Although no marine fossils were got in the cuttings for the Caledonian Canal, it is worthy of note that they have now been discovered near Fort William and Fort George, at both extremities of the great glen.

Glacial clays containing marine fossils of arctic type are scarcely known along the borders of the Moray Firth. Dr. Gordon, of Birnie, tells me the only instances he is aware of are this one at Ardersier and another at Burghead. In the interior of Nairn and Elgin they have not been found.

I met with them, however, some distance to the east of Speymouth, between Cullen and Banff, where the sea-cliffs here and there show deep masses of dark bluish clay, in which remains of arctic shells may occasionally be detected. Further eastward, at Gamrie, they again present themselves, but only to a very limited extent, having apparently been swept out of the little ravines by small glaciers descending from the neighbouring heights. Without this hypothesis it is difficult to account for the patchy manner in which these marine beds have been left there.

In the island of Arran, as has been shown by the Rev. Mr. Watson and Dr. Bryce, we have evidence of submergence to the amount of some hundreds of feet above the present sea-level; but the marine beds have all disappeared from the mountainous part of the island, and even in the lower southern extremity they have been wellnigh destroyed and overwhelmed beneath heavy masses of sand, mud and boulders—the work, as I suppose, of the later glaciers.

Long ago Dr. Scouler pointed out that certain ravines near Dublin had apparently been formed after the deposition of the shelly gravel of that district, from the fact that they are completely destitute of any vestige of this marine gravel, although it ascends to higher levels in the neighbourhood. But he was at a loss to understand on what principle of selection one set of hollows had become receptacles of this shelly drift while others had escaped (Journ. of Geol. Soc. of Dublin, vol. i. p. 266). Afterwards Mr. Oldham, in 1848, in examining this locality and confirming Dr. Scouler's observations, was struck with the same remarkable fact, that several of the glens in Wicklow contain no trace of marine beds, although shelly gravels

surround them on all sides and ascend to much higher elevations; and he further states that the great boulder deposit of Wicklow is perfectly distinct from, and in all cases *subsequent to*, these marine beds (*ibid.* vol. iii. p. 302).

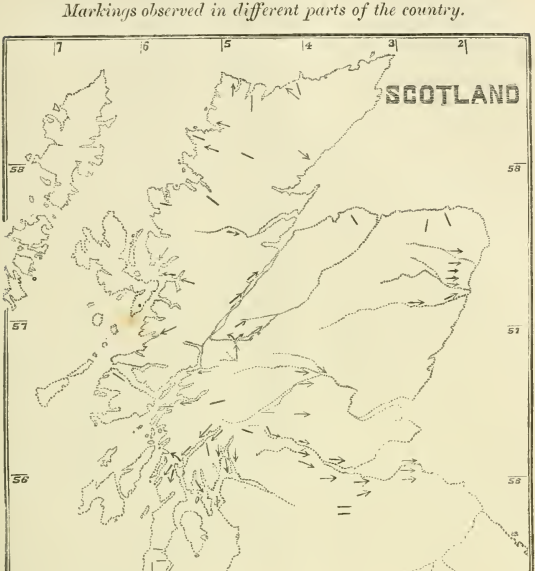
Mr. Darwin was the first to perceive the true meaning of such facts. After studying the similar phenomena of Wales, he pointed out, in 1842, the evidence they afford of the advance of glaciers subsequent to the deposition of the marine beds, showing that when the land had risen to nearly its present height the ice filled some of the valleys near Snowdon, and cleared out the accumulations left in them by the sea. In tracing the phenomena downwards, Mr. Darwin seems to have been unable to say where glacier-action ended and marine action began. Professor Ramsay, who followed up Darwin's observations, and confirmed them by additional details, does not bring his chief Snowdon glacier far down the valley, supposing the lower ground near the sea to be covered with marine drift which the later glaciers have not disturbed; and he looks upon the high-lying flats, at elevations of even 2000 and 2300 feet, as terraces of marine formation, marking pauses in the reelevation of the country (Old Glaciers of Wales, pp. 95–102, and map).

Judging from what I know of Scotland, I am inclined to think the later Welsh glaciers must have been far more extensive than these views would indicate, and that the Snowdon one at least must have come down to the Menai Straits. Mr. Symonds has pointed out many facts which imply the action of land-ice and snow, after the land emerged, not only in various parts of Wales, but also in the Malvern Hills.

As illustrating the nature of the climate I suppose to have prevailed during the time of the later glaciers, let me give the following example.

In the northern extremity of Aberdeenshire there is a hill called Mormond, about 800 feet high, which lies a few miles south of the town of Fraserburgh. It rises out of the low surrounding region like a great mole-heap. Many years ago I had found a good deal of evidence in the neighbouring district of the presence of the sea up to heights of nearly 500 feet, and, among other facts, had noted beds of well-rolled shingle forming the crest of certain low hills, at elevations of from 200 to 480 feet, which seemed to me to have been shoals in the sea of that period. In some of these I got remains of arctic shells. I argued, therefore, that if the sea had covered the land to the height of 480 or 500 feet, as it evidently did, it should have encircled this hill of Mormond, and formed a belt of shingle round it at a corresponding height; or if the submergence was sufficient to completely cover the hill, it ought to show a mass of gravel on the top. I accordingly spent two long summer days in the month of June examining the hill, which is a wide-spreading, heath-covered mass, some eight or nine miles in circumference, bare and brown, without a bush or tree upon it. I was disappointed and puzzled to find no rolled shingle anywhere over the whole surface of the hill, neither on the top nor on the sides of it. But along the base and

Sketch-map of Scotland, showing the Direction of the Glacial Markings observed in different parts of the country.



N.B.—The headless arrows indicate that the side from which the agent moved is not certain.

⟶ Direction of Glacial striæ.

Note.—In this little map I have availed myself of the materials contained in a map of the middle region of Scotland which accompanied an excellent paper by Mr. C. Maclaren in the 'Edinburgh New Philosophical Journal' for 1849, and likewise of various scattered notices by Murchison, Nicol, Milne-Home, Chambers, Forbes, and Smith of Jordan-hill.

skirts I came upon mounds of gravel which did not form a zone or sheet at any regular level, but were disposed in a manner I could not account for by marine action of any sort. Nowhere did they reach to the height of 400 or even 300 feet; and all the top and sides of the hill seemed completely destitute of marine deposits of any kind—no beds of gravel, shingle, sand, or silt—nothing but the angular stony rubbish of the gneiss, quartz-rock, and granite of which the hill is composed.

Mormond is somewhat of a horseshoe-form, by reason of two spurs or ridges it throws out towards Fraserburgh, which enclose a hollow in the northern bosom of the hill. This hollow contains a bed of peat, below which we find coarse grey mud, like what occurs beneath a glacier, full of stones, several of which are ice-scratched. In front of this hollow, at the distance of a mile or so towards Fraserburgh, there is a transverse ridge of gravelly débris (somewhat like a kaim), called the Sinclair Hills, the base of which is not more than 50 feet above the sea. The explanation of the matter I take to be as follows:—This hill was no doubt encircled by the sea, or may have been completely under it during the time of the submergence; but after the waters withdrew, it appears to have been covered by snow and ice, which obliterated all trace of the sea's presence, and carried down the gravelly débris to its outer edge to form the mounds we now see along the base of the hill. The hollow in its northern face was probably occupied by a glacier which stretched further out, the ridge of the Sinclair Hills marking its former termination. Some of this gravel may have been originally of marine formation, and afterwards remodelled by the glacier and by the water flowing from it. In the north-eastern part of Aberdeenshire I find traces of heavy snow beds, or small glaciers of the second order, on the flanks of hills even lower than Mormond; but in most districts these low hills have been overrun by ice from the interior of the country.

§ 4. *Moraines at Low Levels.*

One of the proofs that the glacier and not the sea has been the last occupant of the surface is the occurrence of well-preserved moraines at low levels. Now the goodness of the evidence here depends, first, upon the certainty that the masses in question are really moraines, and, secondly, upon the assurance that they have never been covered by the sea since they were formed. Differences of opinion will, no doubt, exist for some time in regard to both of these points.

When Agassiz visited Dr. Fleming at Aberdeen, in 1840, he was shown some ridges of gravel near the coast, a little to the north of that city, and pronounced them to be moraines. Fleming dissented from this opinion, on the ground that they were of more recent origin than the beds of fine clay beside them, which contain arctic shells. I think Agassiz was right as to the mounds being moraines, and that Fleming was also right, that they were a more recent

deposit than the clay containing the shells. They imply, in my opinion, that the glaciers of the Dee and Don coalesced and reached the coast after the period of submergence—the left flank of the ice lying upon Belhelvie, and the right flank on the hills of Nigg. Assuming that these mounds at Aberdeen are actually moraines of the later glaciers, we ought to be able, on proceeding up the valley of the Dee, to point out the various halting-places of the glacier as it gradually retreated to the mountains. This, I think, can be done. Ten miles up the valley of the Dee we find indications of a halt, a crescent-like band of moraine-matter curving out from the base of the Hill of Fare to the Loch of Drum. At Aboyne (20 miles further up) there are indications of another halt. But the longest and most decided pause has been a little below the village of Ballater, about 40 miles from Aberdeen and 600 feet above the sea. Here there is a great assemblage of mounds on both sides of the river. On the north side they commence at the base of the hill immediately below the Pass of Ballater, and extend eastward past Tullich to Culbleen, where they cover all the ground between the river and the base of the hill, forming a great mass of hillocks and tumuli of various forms. To the eastward of Tullich they reach an elevation of about 400 feet above the river, their upper surface forming a nearly horizontal line or platform, which, however, is not quite horizontal, but slopes slightly to the eastward or down the valley. These moraine-heaps fill all the curve of the hills between Camus o' May and Tullich. The flank of the hill of Culbleen is much bared, and dotted with perched boulders. Here may be seen split blocks of red granite, which may have been broken by tumbling off the end or side of the glacier.

On the south side of the valley, along the base of Pannanich Hill, the higher part of the moraine does not take the shape of hillocks so much as it does on the north side, but forms a great bank leaning against the hill-side, like a rude platform or terrace, strewed with granite boulders, and corresponding in height with the upper level of the moraine on the opposite side of the valley. The granite of the spur of the hill to the east of Pannanich Wells is bare, and dotted with perched blocks, of which there are some fine examples. The rock itself is rounded off into pillowy masses, which are more rugged on their eastern outline; these appearances extend far above the level of the highest moraines. The granite, however, is too much weathered to show the finer glacial markings; and the same remark applies to most of the granite on Deeside. The great sheet of gravel which covers the moor of Dinnet for some miles to the east of Camus o' May has probably been spread out by the waters pouring from the end of the glacier, and issuing from beneath it, aided by occasional floods when the snow and ice thawed extensively.

Other moraines of later origin than this one below Ballater are to be found in the upper branches of the Dee—as, for example, in Glen Lui, near Derry Lodge, at an altitude of about 1600 feet, and still higher up, near the top of Glen Derry, not far from Loch Etichan, at the base of Ben Muick Dhui, probably 2000 feet above

the sea. These mark the last stages of the glacier. Corresponding moraines occur in Glen Dee and in the ravines on the north side of the Cairngorm mountains.

That the glacier of the Dee actually did come far down the valley after the land emerged is also shown by a remarkably fine series of terminal moraines in the valley of the Feugh, which is a tributary of the Dee. These moraines occur at levels of 300 and 400 feet. They appear to be perfectly undisturbed, and, so far as I can judge, have never been touched by the sea since they were formed. Occurring as they do at these low levels, they afford good evidence of the advance made by the later glaciers. The Feugh takes its rise at the foot of Mount Battock (2555 feet), and, after a course of about fifteen miles, falls into the south side of the river Dee, at the village of Banchory, which is eighteen miles from Aberdeen and 150 feet above the sea. On walking up the valley of the Feugh for about a couple of miles we meet with a moraine at a place called Gellan, on the south side of the stream. This moraine must have been formed by the glacier of the Feugh after it had been joined by those of its two tributaries, the Avon and the Dye. The moraine here comes down below the level of 300 feet; and the glacier, at the time of its formation, was about thirteen miles long. Proceeding two miles further up the valley, immediately after passing the mouth of the Dye, we come to a fine moraine at a level of about 300 feet, which must have been formed by the united glaciers of the Feugh and the Avon, when the ice-stream was ten or twelve miles in length. The great size of this moraine marks a very long pause of the glacier here. The quantity of débris is enormous, especially on the south side of the valley, where it forms a range of mounds composed of gravel, sand, and rolled boulders. One of these hillocks, called the Dunimore, is about 120 feet high. In some of these ridges there is a considerable quantity of washed sand, like river-sand; others are composed of blocks and boulders of granite mixed with rough stony débris, while a few consist of a mass of boulders of all sizes up to 3 or 4 feet in length, with a mixture of disintegrated granite. All the material of the moraine on the south side of the valley seems to be derived from granite; but on the opposite side, at Whitestones, much of it consists of gneiss and crystalline schist. This accords with the distribution of the rocks, which are all granite on the south side, but mostly of gneiss on the north. It would seem, therefore, that the débris of the two sides of the valley has been kept from mingling; and this is just what a glacier would do, and not what we should expect had these mounds been heaped together by the sea. In the centre of the valley, which is here very flat, the moraine has been swept away. The river Avon, which joins the Feugh a little above this, is a small stream that also rises at the foot of Mount Battock, and flows along a deep, narrow lonely glen, or gorge, between Clochnaben (1944 feet) and Peter Hill (2023 feet). There is a fine little moraine just outside the entrance to the gorge, at an altitude of about 440 feet above the sea, forming a characteristic crescent-shaped ridge, dotted over with large granite

boulders. There it lies, clear as a sunbeam, just as the glacier left it. I walked up the glen a good long way above this, until I was near the foot of Mount Battock, but observed no other moraines, which would seem to show that the glacier must have shrunk rapidly above this. Here, therefore, as in Lochaber, the glaciers seem to have retreated by stages, pausing for a long time at certain places and retiring rapidly at others. There seems to be a corresponding moraine on the Feugh, near Finzean; and I have no doubt others will be found in Glen Dye, which, however, I had not time to explore.

Terminal moraines (at least what I suppose to be so) also occur on the south side of the Grampians, in localities which imply very intense glacial conditions. Thus in Kincardineshire I observed one at Drumlithie, near the railway station there, at an altitude of 280 or 300 feet above the sea, formed apparently by the glacier of the Bervie, a small stream which takes its rise among hills of from 1500 to 1700 feet in height. When this moraine was formed, the glacier was seven or eight miles long. This moraine, I believe, is locally known as the Kaims of Candy, and seems to resemble the kaims of the south of Scotland, many of which have been described by Mr. Milne-Home, Professor Geikie, and others, and are supposed by them to be accumulations formed underneath the sea by the action of conflicting currents or tides. This kaim at Drumlithie, however, appears to me to be a terminal moraine. It consists of a long narrow mound, or series of mounds, from 20 to 30 feet high, with sides sloping at angles of 20° to 30°, curving in a crescent- or horseshoe-form, with the convexity seawards. So far as I could make out, it is composed of coarse gravelly débris, irregularly piled together. These mounds are most sharply defined at their north-eastern extremity. Outside them (*i. e.* seawards) there are traces of lower and more gently sloping mounds, all under cultivation. A narrow steep-sided mound like this, over which one can easily pitch a stone, curving along for more than a mile in a crooked manner, is not, I think, an accumulation which conflicting tides or currents would make. The action of the sea would rather level such a mound than make it. However, I shall touch upon the subject of the Kaims and Eskers further on.

In the north and west Highlands, where the mountains come near the coast, moraines of a more decided character are often to be seen close beside the sea. Those at Brora, for example, on the east coast of Sutherlandshire, are very striking, and have attracted the attention of many observers. I examined another very good example near Muir of Ord, about ten miles west of Inverness, formed apparently by the right flank of a glacier descending Glen Orrin. Along both sides of the Dornoch Firth I noticed moraine-like masses, which implied that the glacier had come well down the Firth there. The great range of gravel ridges and boulders which runs from Culloden Moor to Kildrummy*, near Nairn, consists, in my opinion,

* *Kildrummy* is a Gaelic word, and probably means the head or end of the ridge, which is very descriptive of the place.

of moraines, and shows that the later glaciers which filled the valley of the Caledonian Canal and the neighbouring glens to the westward reached the head of the Moray Firth.

Many of the moraines that attracted the attention of Agassiz in 1840 were at low levels. The most distinct and well-marked of all he saw in the British Islands were, he tells us, near Florence Court (the seat of Lord Enniskillen), in Ireland. He also mentions as good examples those on the banks of Loch Awe and Loch Etive, especially near Bunaw Ferry; all these must have been formed by the later glaciers. Buckland also pointed out a number in Scotland and England which indicate a very great advance of the ice. Dr. Hooker, in a communication to the 'Reader,' in 1865, mentioned that in the upper valley of the Tees there are huge moraines, as well developed and as clearly marked as any in the Alps or Himalayas, and that the glacier determined precisely the present course of the river and its windings. I am therefore inclined to believe that not only in the north of Scotland, but also in Ireland and much of England, the glacier, and not the sea, has been the last occupant of the surface, and that many of its peculiar features, such as the kaims, eskers, gravel terraces, and unfossiliferous upper drift, will have to be referred to the action of glaciers and freshwater currents. The valley-gravel is well explained by supposing it to have been formed during the gradual and final retreat of the glaciers; and the remarkable absence of the bones of elephants and other large quadrupeds which occur so frequently in the south of England and France is no doubt due to the later occupation of the northern regions by snow and ice.

A great many of the land-locked hollows along the bottom of hills, now occupied by peat-mosses, probably indicate the position of the last beds of snow and ice which lingered there before they finally vanished.

In places where the glaciers did not reach there were probably heavy beds of snow, which would be partly converted into ice at the bottom. These would exert a modifying influence on the surface, and also affect the drainage of the localities they occupied.

Mr. Kinahan reports a well-marked terminal moraine at a height of only 140 feet above the present sea-level, near Bantry Bay, in the extreme south-west of Ireland—a district which enjoys the mildest winter temperature in the British Islands. This moraine, he says, could never have been under water, or it would have been washed out of shape (Proc. Geol. Soc. Dublin, March 14, 1866). Facts like these have not been sufficiently weighed; for if glaciers came down to within 140 feet of the sea at Bantry Bay, what must have been their development in the northern parts of Britain?

§ 5. *Freshness of the Glacial Markings.*

The freshness of the glacial markings on the bare top of many a hill, in localities which betoken an immense development of ice, affords another argument in favour of a late extension of the glaciers;

for we can scarcely suppose that these markings would have stood the action of the weather so long as they must have done had they been imprinted in the period before the submergence. The length of time that has elapsed since then must be enormous; and yet on some hills of 2000 feet, the summits still exhibit the ice-worn surfaces left by the glaciers which overflowed them from the central heights. As no covering of earth or turf seems ever to have protected them from the weather, it is difficult to conceive how they could have escaped destruction so long had they existed before the time of the submergence.

§ 6. *Kaims, Eskers, &c.*

Many of the narrow, steep-sided, curving ridges of gravel, known in Scotland by the name of Kaims*, and in Ireland as Eskers, I believe to be deposits formed along the margin of the later glaciers. The fact of these gravel-ridges being composed of water-worn materials, often stratified, although generally in confused, irregular beds, has induced most people to think that glaciers could have nothing to do with them; and British geologists generally refer them to the agency of marine currents. But in an ice-covered country where precipices and high rocky escarpments seldom occur, and where the hills are comparatively low with gentle slopes, the deposits formed along the margin of glaciers will often be of a gravelly nature, abounding in beds of sand and rolled pebbles having a sort of stratified arrangement. Such is the case in many of the old moraines of the Vosges. A great deal of water escapes from the end of glaciers and pours off their surface during certain seasons; and a glacier many miles in length, when the snows are melting, will abound in streams of running water, which will carry along much gravel and fine sand and produce deposits of irregularly stratified stuff along the sides and at the end of the glacier.

In order to have moraines of rough rocky débris abounding in great angular blocks such as occur in alpine districts, there must be the necessary conditions, viz. alpine heights and rocky cliffs bordering the glacier. Where these occur in Scotland moraines are found of the usual alpine character; but in a region of low undulating hills it would be vain to look for such. I have no doubt the same explanation will apply to many of the Irish eskers. Assuming masses of glacier ice to have covered the mountains of Ireland and also to have occupied part of the central plain of that country, what kind of deposits might be expected to form along their margin, as they gradually melted away? Something very different no doubt from the usual character of alpine moraines. At certain seasons there would be great streams of water running along the margin of

* The word *Kaim* is in Scotland generally applied to a narrow steep-sided mound. Some derive the term from the fancied resemblance to a cock's *comb*; others suppose it to come from the Gaelic word *cam*, crooked, being often applied to a crooked or curving hill (see Dr. Jamieson's 'Scottish Dictionary'). Mr. Campbell, of Islay, derives it from *Ceum*, a path.

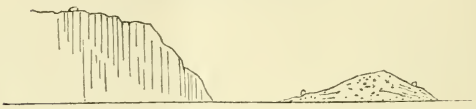
the ice, and pouring off its surface, when the winter covering of snow thawed rapidly. And when the glaciers of the Clyde valley were retreating to the high grounds of Lanarkshire, what sort of deposits might be expected to form in front of them at the time they were pausing near Carnwath or Carstairs? Would they not be something like the Kaims which Mr. Geikie has described as occurring there?

It is not to be supposed that all the ice which gathered over the central plain of Ireland and other low regions of a like nature proceeded from the hills, although glaciers descending from the mountains would, of course, contribute their proportion. For if a great thickness of snow fell, year after year, over the whole surface of the country, and lay there without melting, the bottom layers would be gradually converted into ice, the thickness of which would depend upon the depth of the superincumbent snow. In course of time, as the weight of the mass increased, motion would commence by the ice yielding in the direction of least resistance. The pressure in certain places being unequal, the ice would move (very slowly, no doubt) towards the quarter where the pressure was weakest. This, it is likely, would in most cases be the seaward opening of the chief valleys; and motion having once begun there, would be gradually propagated into the interior of the country.

I have remarked that these Kaims often lie across valleys in long sinuous lines, forming curves or segments of a circle, the concavity of which is presented to the head of the valley, and their convexity towards the sea or downward end, as in terminal moraines. Such would seem to be the case with some of those in the south of Scotland. For example, in the statistical account of the parish of Greenlaw, in Berwickshire, the writer makes mention of certain gravel ridges or Kaims, which he says are "*disposed like a horse-shoe, with the hollow towards the hills.*" Some of the most notable Irish Eskers lie in lines across the vale of the Shannon, as, for example, those between Athlone and Parsonstown. Another sweeps round the northern extremity of the Slieve Bloom mountains; and Sir Richard Griffiths tells us of a large one called the Horseshoe, from its peculiar shape. These linear ridges of gravel seem to be most developed in low districts away from the mountains. In such localities the ice, being unconfined by hills, would spread out into a wide cake or sheet. The time of their formation appears to have been at the close of the glacial period, not during the submergence, but after it, when the icy masses had begun their final retreat. The material they consist of and its mode of arrangement point to streams of water flowing over the surface of the glaciers, and washing the gravelly débris into heaps along their margins. A mass of gravel reposing against the side or end of a glacier would lose its support when the ice melted away, and, falling down in a slope, would assume the form of a steep-sided mound. Glaciers are subject to oscillations, sometimes advancing, sometimes receding, according to the varying nature of the seasons. Suppose the end of a glacier to push forward into a sheet of gravel lying in front, the result would be to force it up into a mound all along the edge of the ice (see figs. 1 & 2).

Fig. 1.—*Terminal slope of a glacier, with gravelly débris resting against it.*

Fig. 2.—*Retreating glacier, leaving a Kaim or Esker.*



M. Collomb mentions that the frontal slope of terminal moraines is generally steeper than that of the other side. In the old moraines of the Vosges this is constantly the case, the frontal slope sometimes amounting to an angle of 35°. Sir Richard Griffith tells us that in the case of the Irish horseshoe Eskers one side generally slopes at an angle of 30° and the other at 10° to 15°.

If the Kaims and Eskers were formed beneath the sea by conflicting tides and currents, how comes it they are so destitute of marine fossils? No satisfactory explanation of this has been given. As most of the Irish ridges are composed of limestone gravel, there would be the less likelihood of the shells being dissolved by the percolation of water. The only shells I ever found in a Kaim were in the parish of Slains in Aberdeenshire. These were old-Crag shells (*Voluta Lamberti* and others), showing, as I conceive, that the formation of the Kaim was long posterior to the time when the mollusca lived which inhabited the shells, and therefore affording no argument that the ridge owed its shape to the action of the sea. The occurrence of these old shells, however, was so far interesting as it showed that, if the gravel of other Kaims had been originally fossiliferous, the shells in them ought not to have all disappeared. The marked absence of marine fossils in the Kaims, Eskers, and upper drift or upper boulder-clay affords a strong presumption that these deposits were not accumulated beneath the sea.

I have also a difficulty in believing that narrow crooked (sometimes even zigzag) ridges of gravel, with their sides sloping at angles of 20° to 30°, would be formed beneath the sea, or at all events could have emerged from it without being thrown down. I should think the materials could not lie at such an angle of repose beneath agitated water, and would have been levelled to some extent as they came under the influence of the waves and breakers. They could not have stood the dash of the water in stormy weather, even in

comparatively sheltered places. The material of which these ridges are usually composed is of a loose incoherent nature; and the present slope of their sides is often as steep as what the sand and pebbles can lie at. Now the angle of repose of such stuff in strongly agitated water is much less than it is in air. Long narrow mounds sloping steeply on both sides could not have preserved this form when lashed by the waves and breakers; and I therefore maintain that when the movement of emergence brought them near the surface of the water they would have been levelled to the angle of repose which gravel beaches usually exhibit.

A large iceberg running aground amongst gravel might cause mounds like the Kaims, but this could take place only in water of considerable depth. Heavy packs of ice driven forcibly ashore might perhaps also give rise to similar ridges, although scarcely, I should think, of such great dimensions. But unless the mounds were formed high up on the beach beyond the extreme limit of the tide they would be levelled again by the return of the waves. If formed in this way they should also contain some littoral shells, and their curves ought, as a rule, to present the convex side to the land, and not to the sea. The sea cutting into the face of a bank may no doubt cause a steep slope on one side, but not a narrow crooked ridge, steep on both sides like a railway embankment.

The Swedish *Osar** and the American *Horsebacks* seem to resemble the Kaims and Eskers in their linear character, gravelly composition, steep sides, and want of fossils. Sir Charles Lyell, in his account of the Swedish Osar, says he met with only one instance of shells occurring in them, viz. in the top of a ridge near the Castle of Upsala; but as the species he mentions consist of edible mollusca (mussels, cockles, and periwinkles), there may be a doubt as to whether their presence in this very exceptional instance has not been due to some accidental cause. Agassiz, in his description of the glacial phenomena of Maine, says the *horsebacks* "are unquestionably of a moraine nature, and yet they are not moraines in the ordinary sense of the term." Some of these horsebacks run from north to south; but occasionally they trend from east to west. "This," he says, "is the case where a morainic accumulation of loose materials may have been pushed forward along the margin, in front of an extensive sheet of ice moving southward, and then left unchanged by the subsequent retreat northward of the whole mass. I conceive that such horsebacks running east and west may be compared to terminal moraines, which, as is is well known, owe their origin to oscillations of the front end of a glacier pushing forward a mass of loose materials, thus throwing it up into a transverse ridge, and then melting away to some point further back." (Agassiz in the Atlantic Monthly, Feb. & March, 1867). He makes no mention of any marine fossils occurring in these horseback ridges, and does not seem to think that the sea was concerned in their formation. I may also mention that some of these American ridges occur in the region of

* Under the name of *Osar* it would seem that deposits of more than one kind have been described, perhaps of different ages and various modes of formation.

the freshwater drift of the Western States, where we can scarcely suppose the sea to have operated.

As the later glaciers in Britain and Ireland in many cases must have moved over sand and gravel previously accumulated by the sea, it is evident that their marginal deposits would be influenced by this circumstance; for the gravel and pebbles in front of them might have been originally waterworn by the waves, and some marine shells might thus be occasionally found in them. The occurrence of such remains in a few Eskers I would therefore consider to be no material objection to my mode of accounting for them. In reference to the waterworn and pebbly character which many of these glacial accumulations present, it may be useful to bear in mind that deposits of similar materials are common in Switzerland, and that even the famous blocks of Monthey lie amongst stratified sand and gravel.

§ 7. *Gravel Terraces.*

The terraced banks of sand and gravel that occur along the sides of our Scottish rivers seem to me to have been formed during the close of the glacial period. Some geologists have attributed them to marine action, and have considered them to be ancient sea-margins. I myself, at one time, endeavoured to account for many of these gravel accumulations by the off-rushing action of the sea during movements of upheaval at the time the land was gradually emerging from the sea of the glacial period, which we know covered much of Great Britain. But I have become convinced that this explanation is not the right one, and I now incline to think they are almost all freshwater and glacial deposits.

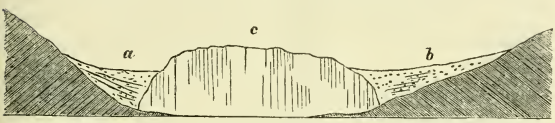
Not a single marine fossil has been found in them. Not a trace of old estuary mud occurs along the higher reaches of our rivers in connexion with them. Now it seems to me that if the sea had occupied a valley after the glaciers finally left it we ought to find some marine fossils and estuary beds here and there along the valley. The absence of all organic remains, terrestrial as well as marine, in these terraces and valley-gravels, agrees better with the supposition that Scotland was at the time covered with snow and ice. Moreover these river-terraces are not horizontal, as they ought to be if they were sea-margins; for as a rule they slope seawards, like the bed of the present rivers*. They occasionally contain large heavy boulders, 3 to 4 feet in diameter or more, and are associated with elongated mounds and confused hillocks of coarse gravel of a more morainic character. I am of opinion, as I have expressed in former papers, that these deposits have been for the most part accumulated during the gradual retreat and melting of the later glaciers. That such terraces and mounds can be formed without the presence of the sea is very well shown by the similar deposits that occur in the valleys of the Pyrenees, the Himalaya, and other mountain-chains in

* For a good account of some Scottish terraces, see a paper on the Old River-terraces of the Earn and Teith, by the Rev. Thos. Brown. Trans. of Royal Society of Edinburgh, vol. xxvi., 1870.

the interior of continents, where we have reason to believe no sea has entered since the glacial period.

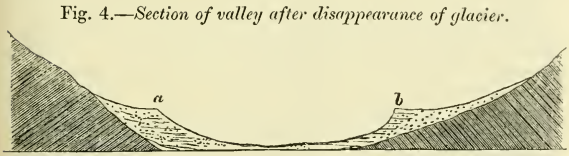
I have fancied that some of these terraces may have originated in the following manner. Suppose the channel of one of our Highland rivers to be occupied by a retreating glacier when the climate was gradually growing milder. During warm seasons, when much snow was melting, gravel, sand, and other débris would be washed down the hill-sides and lodge against the flank of the glacier. The rivulets and streams would at such times come down from the neighbouring heights, carrying with them much matter of this sort. At present it all finds its way into the bed of the river; but when the channel was occupied by a glacier this débris would be arrested by the mass of ice and lodge in the depression between the glacier and the hill (fig. 3). This hollow would therefore be gradually filled up and might be traversed at times by streams of water. When the glacier melted, the mass of stuff resting against it would lose its support and fall down in a steep slope, thus giving rise to the terraced banks we now find (fig. 4).

Fig. 3.—*Section of valley with glacier in retreat.*



c. Glacier. *a* & *b*. Gravelly débris lodging between the glacier and the sides of the valley.

Fig. 4.—*Section of valley after disappearance of glacier.*



a, *b*. Gravel terraces.

It is a mistake, therefore, to refer all these gravel terraces and platforms of stratified material to the action of the sea, as geologists have sometimes done, forgetting that the sea is by no means essential to their formation. The total absence of marine fossils ought to caution us against such hasty inferences. Extensive beds of stratified gravel, sand, and silt seem to have been formed in all countries that were formerly occupied by glaciers.

I conceive that in many of the valleys the bed of the stream might be wholly occupied by ice, the rivers being frozen nearly from top to bottom—and that, on the approach of summer, a great quantity

of snow would be melted before the ice in the central trough of the valley broke up, so that heavy floods of turbid water would be let loose over the surface of the frozen rivers and thus rise to great heights along their banks. The thick solid ice occupying the bed of the stream would take longer to melt, but would gradually break up, rising to the surface in great masses, and bringing with it stones and pebbles from the bottom. These masses of ice would float down the stream, dropping the boulders here and there as they dissolved. When the Straits of Dover were dry land and the rivers wandered away down far below the present coast-line, it is probable that during the winter season the Seine, the Somme, the Thames, &c. would be completely frozen along what are now the lower reaches of these rivers, and at the break up of the snow in summer these frozen masses would cause the river-floods to rise to heights which now appear very marvellous.

Mr. Prestwich has discussed this subject in an excellent manner in the 'Philosophical Transactions' for 1864, p. 286; and I would only suggest that he has perhaps not sufficiently allowed for the unmelted ice in the bottom of the valley, forcing the floods to reach a height they could not otherwise do.

The underground ice of Siberia may have been buried in this way by the rivers flooding it and flinging down beds of mud on it before it had time to melt and become detached from the bottom.

§ 8. *Comparative Glaciation of East and West Coasts.*

I have often been struck with the remarkable intensity of the glacial action displayed on the rocks of the west side of Scotland compared with the east, and in a former paper* I threw out the suggestion that the precipitation of snow along the west Highlands had probably much exceeded what fell on the eastern slope of the island, just as takes place now in regard to the rainfall. Thanks to the Meteorological Society of Scotland, we have now accurate data concerning the rain; and Mr. Buchan's excellent papers on the subject show us what an immense excess there is in the quantity that falls on the west side of the country compared with the east. There are several stations in the west Highlands where the annual rainfall exceeds 100 inches, whereas along the east coast it ranges generally from 25 to 30; and it is interesting to note that the glaciation of the rocks corresponds in intensity with the present excess of the rainfall, showing that the precipitation of snow had been similarly distributed; and is it not the case generally that the marks of ancient glaciers are most decided where the rainfall is now heaviest?

The prevailing wind in Scotland is the south-west, which, sweeping up the moisture from the Atlantic, is cooled as it rises over the mountain-tops of the west coast and throws down its burden in copious showers on those hills, so that before it reaches the eastern side of the island it is a comparatively dry wind. This is well seen

* Quart. Journ. Geol. Soc. xix. p. 258, 1863.

along the line of the Caledonian Canal. Fort William (at its south-west extremity) is one of the wettest places in Scotland, while Culloden (at the north-east end) is one of the driest—86 inches of rain falling at the one, to 25 at the other; while in the Glen Quoich, near the summit level of the canal, 102 inches are recorded in the course of a year.

Can we doubt that in the Glacial period a similar inequality must have existed in the fall of snow? and must not the glaciers fed by three times the quantity of snow have been much heavier and more erosive than those in the eastern valleys? Braemar, at the head of the river Dee, in Aberdeenshire, although embosomed among the highest mountains in Scotland, has a rainfall of only 33 inches in the year, while some of the Argyleshire glens have more than a hundred.

The absence of erratic phenomena along the Ural chain and Siberia generally may perhaps be traced to the well-known dryness of the air and lack of snow in that region.

Many of the singular features in the glaciation of the British Islands seem to be due to excessive falls of snow along the western hills and valleys, in the localities probably where the heaviest rains now occur. The phenomena of the Parallel Roads of Glen Roy, for example, if we are to explain them by the agency of glaciers, require us to suppose that the ice was much more developed on Ben Nevis and the region to the west of the Caledonian Canal than in the hilly district around the sources of the Spey. But the mountain-ridge that lies between Loch Laggan and Loch Spey is quite as lofty as the hills which encircle Loch Arkaig, if not more so—four of the summits exceeding 3000 feet, and one of them being no less than 3700. Yet it is evident the glaciers proceeding from this ridge were much smaller and waned sooner than those that blocked the mouths of Glen Gluoy and Glen Spean; otherwise they would have occupied the watersheds or cols and also the top of Glen Roy at the time the terraces show that these places were clear of ice. Now what we know regarding the rainfall of the district harmonizes remarkably with these results. We have the records of three gauges in the neighbourhood of Ben Nevis and Loch Arkaig—namely, one at Fort William, another at Glen Quoich, and a third at Inverie near Loch Nevis; and the annual rainfall at each of these places is 86, 102, and 82 inches respectively, being an average of 90 inches in the year, whereas at Laggan, near the head of the Spey, the annual amount of rain is only 46 inches, or just about half of this.

Again, there seems reason to believe that the upper reach of the Moray Firth was at one time occupied by a large glacier composed of the united ice-streams issuing from all the glens of Ross-shire and Inverness, which now pour their waters into the Moray and Dornoch Firths. This great glacier seems not only to have occupied the top of the Moray Firth, but to have spread eastward past Nairn and Elgin to near Speymouth, as if the glaciers descending from the district lying to the east of Inverness (now remarkable for its dry climate and small amount of rain) were comparatively so small as to be overborne and pressed aside by the heavier ice issuing from the

western glens. The absence of marine fossils in the drift of Elgin and Nairn favours the supposition that this glacier may have existed even after the time of the submergence. A belt of gravel and boulders, forming kaim-like ridges, which may be traced from the neighbourhood of Inverness eastward along the base of the gneiss hills of Nairn and Elgin to near Speymouth, may perhaps mark the southern edge of this great glacier. It is cut through and partly washed away by the rivers that now cross its path; but although some have regarded it as an old sea-terrace, no marine fossils have have ever been found in it to substantiate that opinion. Now the climate of the country to the east of Inverness is at present one of the driest in Scotland, the yearly fall of rain at Culloden and Nairn being only 24 inches, while in the western glens of Ross and Inverness the rainfall is very heavy. If, therefore, we suppose the fall of snow to have been similarly proportioned, it would help to explain how it came to pass that the western glaciers were so large as to overpower and press aside those of the eastern district. The transport of boulders and denudation of the surface over the low grounds of Morayshire imply the action of some great force passing from W. to E., such as would arise from the flank of a glacier moving down the Moray Firth as I have supposed.

Consider, again, the wonderful facts connected with the glaciation of Ireland made known lately by Messrs. Kinahan and Close, and by Mr. Campbell, of Islay; do they not imply an excessive snowfall along the western heights of that island, and, it may be, a comparatively high elevation of all the western side of the country? And the dispersion of the boulders of Shap granite from Wastdale Crag in the north of England would admit of a clearer explanation if we supposed that the region of the lakes, now so noted for its immense rainfall, was formerly distinguished by a like excess of snow.

I incline to think that the Glacial period, in this country at least, was distinguished by enormous falls of snow as well as by a low temperature. If we might suppose that during summer the elephant, rhinoceros, and other wild animals browsed along the borders of the ice-covered region, it seems likely that they would be sometimes caught in the early storms of approaching winter, when these happened sooner than usual, and thus get bewildered and smothered in the heavy snowdrift. Their short-legged heavy carcasses would ill fit them for wading through deep wreaths of snow; and this would account for the frequent occurrence of their remains in comparison with those of the lighter and fleeter animals. When these large heavy beasts lost themselves amongst the snow and sunk in it, they would be covered up until the summer thaw came, which would float off their carcasses and carry them down the rivers, lodging them in the silt and gravel along their course.

§ 9. *Conclusion.*

This last phase of the Glacial period was therefore no time of mere local glaciers lingering among some of the higher mountains, but the

return of a great ice-sheet which spread over nearly the whole of Scotland and Ireland and also the greater part of England. But the ice seems not to have been so thick and extensive as it was in the early glaciation—nor so enduring; for it has failed to destroy all the beds of clay and sand containing arctic shells which the sea left behind it, whereas in Scotland we find that the ice of the former period cleaned off every thing down to the hard rock. I would suppose that all the mountain-ranges of Scotland and Wales were coated with thick ice, which reached the coast in most places, likewise the hilly ground of the north of England, including the Pennine ridge along its whole length as far at least as Derby. In the lower districts of England further south, there would probably be extensive snow-beds, more or less converted into ice at the bottom. During the summer thaws these would send out great streams of muddy water, occasioning those superficial deposits of brick-earth, warp, and loess which are so widely spread to the southward. Beds of gravel would be lodged where the force of the current was stronger, and when the thaw was unusually rapid. That there must have been heavy beds of consolidated snow even in the extreme south of England, I infer from the fact that I find traces of such in my own neighbourhood, in the low eastern part of Aberdeenshire, on the flanks of hills only a few hundred feet in height. In the low ground in front of these places there is generally a land-locked hollow or shallow basin occupied by peat.

This second ice-sheet gradually shrank into smaller and smaller compass, separating by degrees into valley-glaciers, which paused for a time here and there in their retreat, leaving Kaims and Eskers in the low grounds and more distinct moraines in the mountain-glens. At times the ice seems to have receded rapidly over a wide area without leaving any marginal deposits. In these places the surface is more or less covered with a sheet of coarse earth or mud mixed with stones, which formed the bed or lair of the ice. During such times there probably occurred a succession of warmer seasons, causing a considerable thaw, when vast bodies of water would flow down the valleys, spreading out much gravel, sand, and silt along their course. But it is important to observe that no great submergence of the country again occurred, nothing but that slight depression which is marked by the estuary beds and raised beaches a little above the present coast-line.

The last great modification of the surface has been subaerial, and not submarine. Glaciers, frost, and rain have done the work, not the waves of the sea.