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ON THE

PARALLEL ROADS OF LOCHABER;

WITH

REMARKS ON THE CHANGE OF RELATIVE LEVELS OF
SEA AND LAND IN SCOTLAND,

AND OF THE

DETRITAL DEPOSITS IN THAT COUNTRY.

BY

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On the Parallel Roads of Lochaber, with Remarks on the Change of Relative Levels of Sea and Land in Scotland, and on the Detrital Deposits in that Country.
By DAVID MILNE, Esq.

There are few questions in geology which have given rise to so many theories, and so much speculation, as the origin of the parallel roads in the valleys of Lochaber.

In the year 1817, the late Dr MACCULLOCH gave an elaborate description of them, in a paper read before the Geological Society of London. In the year 1818, Sir THOMAS DICK LAUDER read before the Royal Society of Edinburgh a paper, full of equally interesting details. Both of these observers suggested, in explanation of the shelves which mark the mountain sides of these valleys, that they had been occupied by lakes, which, by earthquakes or other violent convulsions, had been drained. This theory was generally received, until, in the year 1830, Mr DARWIN, so justly celebrated as a geologist, and an accurate observer, published his views, and pronounced the shelves to have been formed by the sea: an opinion which, besides being rested on proofs derived from the locality, he enforced also by his observation of similar appearances in South America.

Mr DARWIN's opinion has received the assent of Sir RICHARD I. Murchison, Mr LYELL, and Mr HORTON, all successively Presidents of the Geological Society, besides other geologists, both at home and abroad, who are justly regarded as authorities in physical science. Relying on the soundness of their views, I confess that when I went to Glen Roy, in the year 1845, it was with a strong conviction that the lake theory was indefensible; a view to which I was the more inclined, from having studied certain marks along different parts of the Scottish coast, on both sides of the island, which satisfied me that the sea had recently stood at a much higher relative level than at present; and that, in its recession, it had formed, all round our coasts, shelves or beach lines, very analogous to those in the Lochaber valleys. I had not been two days in Glen Roy, before I satisfied myself that these views were inapplicable to the shelves in it and its associated valleys. But I was unable, during my visit of 1845, to remain long enough to obtain evidence of the manner in which the lakes had been dammed up, and eventually drained. I therefore resolved to defer the farther consideration of the subject, until I could pay a second visit. This I accomplished in September 1846, when I spent a week in the examination.

In the following paper, I shall attempt to explain my reasons for thinking

Mr DARWIN's theory inadmissible, and to point out the manner in which, as it appears to me, that the lakes were drained,—not as supposed by Dr MACCULLOCH and Sir THOMAS DICK LAUDER, by convulsions of nature, but by the gradual operation of ordinary causes.

Though it is the principal object of this paper to account for the formation of the Lochaber shelves, there are no views regarding them which can be suggested, which have not a more general bearing, and the soundness of which may be tested by evidence supplied from other sources. Former writers, accordingly, and especially Mr DARWIN, have felt it to be necessary, after giving their explanation of the parallel roads, to show, that the principles on which it rests, are, at least, not inconsistent with any established truths in other branches of geology.

I shall not shrink from subjecting the Lake theory, which I have to submit, to a similar ordeal; and the more so, as I feel satisfied that it receives great support from geological considerations now held to be well established.

As the whole details of the parallel roads have been fully described by former writers, I shall limit myself to points on which I have obtained new information, or with regard to which doubts have been expressed.

1. One of the points of the class last referred to, is the absolute horizontality of the shelves. Mr DARWIN, referring to Sir THOMAS DICK LAUDER's observations on this point (p. 76.), hints at the possibility of errors and omissions in the calculation. M. BRAVAIS, in his paper on the lines of former sea-level in Finmark, suggests, "that an accurate geodetic levelling should be applied in the case of the doubtful lines in Scotland," evidently referring to Glen Roy. Mr HOARER, the president of the Geological Society, in his last year's address, observes: "Mr DARWIN's explanation of the parallel roads of Glen Roy, that they are ancient sea-beaches, appears to be now generally accepted; and it would be most interesting, if it were ascertained by exact levellings, such as those of M. BRAVAIS, whether they really are parallel." Similar doubts had been expressed by Sir R. I. MUNICHON, Mr HOARER's predecessor, in his anniversary address of 1843; in support of which, he refers to the concurrent opinion of M. de BRACMONT and Professor PHILLIPS.

In accordance with the doubts expressed by these authorities, the Geological Section of the British Association, at their last meeting, agreed on an address to Her Majesty's Government, requesting them to cause the parallel roads of Lochaber to be examined by the officers of the Ordnance Survey, to ascertain their supposed horizontality.

I have no doubt that the result of this official survey, if made, will be to establish the absolute horizontality of the shelves. In August 1844, Mr D. STRICKSON, at my request, was so obliging as to examine them, and the conclusion at which he arrived, is explained in a letter to me, from which I make the following extracts:—"I have had a number of levels taken, the particulars of which I shall

give you afterwards. The result, I think, leaves no doubt as to the perfect horizontality of the 'roads.' The glen is much more extensive, both as regards length and breadth, than I anticipated, and the height of the roads above its bottom is also very considerable, and any thing like a series of cross sections, referred to the same datum, would be a work of very great magnitude; a month, I should say, would not complete it. The whole we have been able to do, therefore, is to test the uniformity of the levels of the different roads, by viewing them with a good instrument from several points, as was done by Sir THOMAS DICK LAUDER; and, in addition to this, a section was made along the middle road, where it is pretty well defined from Glen Turret downwards, for a distance of nearly $3\frac{1}{2}$ miles, and throughout that stretch, the road was found to be perfectly horizontal." . . . "If I had seen that any thing further could be done, I would have left my assistants for a few days longer; they were there a week."

These observations of Mr STEVENSON, whose professional accuracy is undeniable, confirming, as they so completely do, the result of Sir THOMAS DICK LAUDER'S survey (and he, too, was aided by an engineer), leave no doubt in my mind, as to the horizontality of the roads. It is scarcely necessary to refer to any further and weaker testimony on the subject. But it may be proper to add, that during the two occasions when I visited Glen Roy, I had a pocket-level with me, which I constantly used; and that on the last visit I was accompanied by Mr R. CHAMBERS of Edinburgh, who had a larger spirit-level, and we never could detect any deviation from horizontality.

2. There is a point of some importance bearing on the theory of the shelves, about which former observers have disputed. MACCULLOCH found by his barometric observations, that the Glen Gluoy uppermost shelf is 12 feet above the highest in Glen Roy; but he attributed this difference to errors of observation, and his theory in regard to the formation of the shelves proceeds expressly on the assumption, that these shelves are precisely on the same level. Sir THOMAS DICK LAUDER mentions, however, that Mr M'LEAN, the engineer who assisted him, made the Glen Gluoy shelf 12 feet above that in Glen Roy, whilst Sir THOMAS himself made it 15 feet. According to the observations made by myself and Mr CHAMBERS last September, the difference is much greater. By levelling, we made it 23 feet; by joint barometric and sympiesometer observations, I made it 23 feet.

3. Whilst on the subject of Glen Gluoy, I may mention that I discovered in it a second shelf, which the barometer shewed to be 200 feet, and the sympiesometer 212 feet, below the level of the one before referred to. I detected it first immediately above the mouth of Glen Fintec. It is traceable on both sides of the glen, and for several miles upwards.

4. There is a circumstance of great importance, in the theory of these roads, on which I was so fortunate as to obtain farther information. I allude to the fact, that most of the shelves are coincident with some summit level, so as to ad-

mit of the waters flowing over that level as over a lip. Thus the uppermost shelf of Glen Glasy No. 1, in Sir THOMAS DICK LAUDER'S Memoir, is (as he explains) exactly coincident with the water-shed ridge which divides Glen Glasy from Glen Roy, so that the waters (whatever they were) which stood at that height and formed the beach No. 1, must have flowed out at the head of Glen Glasy into Glen Roy. In like manner, the uppermost shelf in Glen Roy, No 2 in Sir THOMAS DICK LAUDER'S Memoir, is (as he also mentions) exactly coincident with the water-shed ridge which divides Glen Roy from the valley of the Spey; so that the waters which stood in Glen Roy at No. 2 beach, must have flowed over the head of the Glen into Spey valley. In like manner, the only shelf which occurs in Glen Spean, No. 4 in Sir THOMAS DICK LAUDER'S Memoir, is exactly coincident with, or rather is a few feet above, the pass of Mukkal at the head of Loch Laggan, through which pass, the waters standing at the level of No. 4 must have flowed eastward into Spey valley. These coincidences, as Mr DARWIN admits, "are so remarkable, that they must (I use his own words) be intimately connected with the origin of the shelves; although such relation is not absolutely necessary, inasmuch as the middle shelf of Glen Roy, is not on a level with any water-shed." (P. 43.)

The middle shelf here alluded to is No. 3 in Sir THOMAS DICK LAUDER'S list. The discovery which I made, was its exact coincidence with a water-shed at the head of Glen Glaster, a glen which, though branching up from Glen Roy near the bottom of it, oddly enough does not appear to have been visited, and certainly not to have been described, by any former observer.

Shelves 3 and 4 are the only shelves which enter and run up this glen. Sir THOMAS DICK LAUDER'S map inaccurately represents shelf 2 as marking it on both of its sides. Shelf 2 stops, however, on both sides of Glen Roy a little to the eastward of, or above the mouth of Glen Glaster.

In following shelf 3 to the head of this glen, I found that it was there lost in a low mossy flat. A little beyond this flat, and a few feet below the summit-level, an *old river-course* can be distinctly traced down a slope towards Loch Laggan. It has a rocky bed, over which a *great body of water* had evidently flowed at some former period. The breadth of the rocky bed is from 30 to 40 feet; the knolls of rock are from 2 to 5 feet high, and amongst them are rounded blocks of stone, such as occur in all great Highland rivers. I traced this rocky channel for about a mile towards Loch Laggan; and I afterwards found the place where it had discharged its waters into Loch Laggan, when that loch stood at shelf 4. It is marked by a huge delta, forming a projecting buttress at the level of that shelf, and bulging far beyond the general side of the Laggan valley.

On examining the rocky knolls attentively in this ancient river-course, I found that the smooth faces were all towards Glen Glaster, and the rough faces in the opposite direction, affording proof, if such were needed, that the stream which flowed there had come from Glen Glaster.

A small rivulet trickles now among the rocks, infinitely too feeble to have produced the appearances.

It is now, therefore, established, not only that the whole of the 4 shelves of Lochaber are coincident with water-sheds respectively, but that a great body of water had filled Glen Glaster, and of course Glenroy, the outlet of which was down this ancient river-course to shelf 4 in Loch Laggan, which is at a lower level by 212 feet.

Whilst on this subject, I may mention farther, that I examined narrowly the interval of space between shelf 1 at the head of Glen Gluoy, and shelf 2 at the head of Glen Turret, where the last shelf is nearest to Glen Gluoy. This space also appeared to me to exhibit the features of an ancient river-course, though they are not so striking as those just described. The distance from the one shelf to the other, is about a mile. Where the Glen Gluoy shelf ends, rocky knolls rise above the moss, water-worn below the level of the shelf, but rough above that level. Their smooth faces are all towards Glen Gluoy. Near shelf 2, in Glen Turret, the rocks have evidently been excavated and cut into by some considerable stream; at present a very small burn runs in this rocky channel, quite incapable of producing the appearances.

The grandest exhibition of an ancient and deserted river-course is, however, at the head of Loch Laggan. The Pass of Mukkul is a channel, the bed and sides of which are entirely rock. It is, at its narrowest part, about 70 feet wide, the wall faces being on each side from 40 to 50 feet high. The rocks at the sides are evidently water-worn for about 30 feet up. To the eastward, this gorge expands into a broad channel of several hundred yards in width, divided in the middle by what has formerly been a rocky islet, against which the waters of this large river had chafed in issuing from the pass. For nearly a mile towards the east, the rocky banks continue on each side, but they gradually diverge, having between them a mossy flat sloping gently eastward. The smooth faces of the rocks within the probable reach of the river-waters, are all towards the west, where Loch Laggan is situated. The height of shelf 4 above the highest point of this deserted channel, is, by barometric measurement, about 21 feet, which affords, therefore, some probable estimate of the average depth of the river. I have only to add, that no stream whatever now occupies this water-course, except where, for a short part of it, the river Fattaig flows in a reverse direction into the head of Loch Laggan. This stream was, when I visited it last September, only about 18 inches deep and 30 feet wide, and must be quite inadequate to have formed the rocky banks on each side of it.

The ancient river-course now described is of much greater size than that at the head of Glen Glaster, just as the Glen Glaster river-course is of greater dimensions than those respectively at the head of Glen Gluoy and Glen Roy. The reason is obvious. The river at Mukkul had to discharge not merely the waters

which belonged to Glen Spean, but also those which flowed out from Glen Glaster, comprehending Glen Roy, Glen Collarig, and Glen Gluoy. The Glen Glaster river-course discharged the waters of Glen Collarig, Glen Gluoy, and Glen Roy, whilst the Glen Gluoy stream discharged only the waters of one lake. Mr DARWIN did not visit the Pass of Makkul. If he had studied the appearances presented by it, and by those almost as strikingly exhibited at Glen Glaster, he would have found it impossible to deny that the waters which formed shelves 2 and 4 flowed down river-courses, and therefore could not be arms of the sea.

His proposition is, "that the waters of the sea, in the form of narrow arms or lochs, such as those now deeply penetrating the western coast, once entered and gradually retired from these several valleys;" and he adds, that after considering the "several and successive steps of the argument, the theory of the marine origin of the parallel roads of Lochaber, appears to me *demonstrated*." (P. 56.) I regret that Mr DARWIN should have expressed himself in these very decided and confident terms, especially as his survey was incomplete; for I venture to think, that it can be satisfactorily established, that the parallel roads of Lochaber were formed by fresh water lakes.

1. The first circumstance which I shall notice as fatal to Mr DARWIN'S theory, is suggested by the fact last referred to, that the waters which formed the different shelves, must have *flowed out of the glens, and descended by river-courses to lower levels*. The waters which formed No. 1 shelf in Glen Gluoy descended nearly 20 feet by flowing into Glen Roy. The waters which formed No. 2 shelf in Glen Roy flowed in like manner into the valley of the Spey. The waters which formed No. 3 shelf were discharged over the head of Glen Glaster, down a slope of about 212 feet in vertical height, into Glen Spean. Lastly, the waters which formed shelf 4 in Glen Spean, issued out of Loch Laggan by the ancient river-course at Makkul.

Now, any one of these cases is irreconcilable with the notion, that the shelves had been formed by arms of the sea. There is no such thing in nature as a river flowing out of an arm of the sea, to a lower level.

Mr DARWIN, as we have seen, admits that this coincidence of the shelves with water-sheds, must be in some way connected with their origin; and, accordingly, he endeavours to give an explanation of it consistently with his theory. He says that these water-sheds are *land straits*, with sea on each side of them, and that they consist of littoral deposits or accumulations of matter formed by the opposition of tides. This opinion, however, is altogether inconsistent with the actual circumstances of the case. In the first place, there is at these water-sheds, no accumulation of littoral deposits or detrital matter. They consist, generally, of bare rocks, forming sloping channels or water-courses. In the second place, there is no trace of water at the same level, on each side of these water-sheds. In the third place, when land straits are formed by the accumulation of matter from opposition of tides, it is not in situations like the heads of glens which narrow to a point, and

at that point are separated by a small neck of land,—it is where there is space for a considerable current on each side of the strait.

For these reasons I consider that Mr DARWIN's explanation of the coincidence of the shelves with the water-sheds before described, is quite inadmissible.

2. The second serious objection to Mr DARWIN's theory arises from the fact, that *the shelves in the different glens are not coincident in level*. If they had been formed by arms of the sea, as the land rose out of it, the sea should have formed lines in all the valleys which it entered, at precisely the same levels. But neither of the Glen Gluoy shelves is to be seen, in any of the other valleys. So also the No. 2, or highest shelf of Glen Roy, and the next lowest, or No. 3, do not occur in the lower part of that glen, or in the adjoining valleys of Glen Gaster, Glen Spean, and Glen Troig.

Mr DARWIN attempts to explain one, but one only, of these circumstances, viz., the difference of level between No. 1 and No. 2 shelves, by a theory of very questionable soundness. He says, that the tide in Glen Gluoy may have risen 20 feet higher at the head of the estuary, than at the head of Glen Turret. It would be necessary that it should rise 20 feet higher. But if this were the case, then the shelves, at all events, in Glen Gluoy, would not be horizontal, or nearly so;—they would have sloped upwards towards the head of Glen Gluoy, by 20 feet in the course of 8 or 7 miles,—the length of the glen. But this would be inconsistent with the great and well-established fact so characteristic of these Lochaber shelves; and moreover, though the beach-lines at the heads of the two glens might not be exactly coincident in level there, they ought, at all events, to be so at the mouths of the glens where the supposed arms of the sea joined the main body of the ocean,—which is not pretended.

This theory, however, would explain merely the non-appearance of shelf 1 in Glen Roy. The non-appearance of all the others is accounted for by Mr DARWIN, simply by supposing that something or other had prevented them being marked in the other glens.

In support of this view, Mr DARWIN refers to two intermediate shelves which are faintly traceable on Tomhavan and elsewhere, in order to show that the water did produce marks at some places, and not at others. But, from the faintness of these intermediate lines, it is manifest that the water had stood at their level for a much shorter period than at the levels of the principal shelves; and, therefore, no fair inference can be drawn from the former applicable to the latter.

3. These considerations suggest, however, a separate and even a more serious objection. Not only should the sea have made markings at the same levels in all the Glens of Lochaber, but it should have produced *similar appearances, and at the same levels respectively, on all the mountains of Scotland, high enough for the purpose*. Mr DARWIN says, "that it would be more proper to consider the preservation of these ancient beaches as the *anomaly*, and their obliteration from meteoric agency the ordinary course of nature." (P. 60.) Supposing him right in

this, he ought to have shown how circumstances caused that anomaly at Glen Roy and its adjoining valleys. But he has not shown, and cannot show, that the sides of the Glen Roy mountains are in any respect different from those other highland mountains. Indeed, he has himself pointed out a similar beach line at Kilmunnin, in a glen towards Inverness. I take leave farther to doubt the soundness of Mr DARWIN'S proposition, that the preservation of ancient beach lines is anomalous. The whole of Scotland, and I believe also of the British Islands, is begirt with lines of ancient sea beach.

4. The ancient sea beaches, now alluded to as existing along our coasts, present a very marked contrast with the Lochaber shelves. If these shelves had been formed by the sea, it will, I presume, be admitted that, considering their great altitude, they are of much older date than beach lines at a lower level. *If older, then they should be less perfect and entire.* But the contrary is the case. They are incomparably more perfect and entire than any of the lowest ancient sea terraces which occur along our coasts.

5. If the Lochaber roads were formed by the sea, the well-known actions of the tides, to which Mr DARWIN refers, would have precluded the formation of them along lines absolutely horizontal.

Mr DARWIN refers to a case in South America, where, in 18 miles, the tidal wave rises at one place 20 feet higher than another in the same estuary. Nearer home, in the Bristol Channel, the sea rises at its head about 50 feet higher than at its mouth.

The tide at Blackwall rises 12 feet higher than at Yarmouth. In the Firth of Tay, the tide rises at Perth 18 inches above the level at Newburgh. The tide at Alicia is said to rise 2 feet 9 inches above its level at Leith. At Glasgow, the tide rises 10 or 11 inches above its level at Greenock. On the Dee, the level of high water is, at Chester, 8 inches above what it is at Flint, near the mouth of the river, a distance of 11 miles.

On this principle, the beaches of Lochaber, if formed by arms of the sea, ought all gradually to rise to the head of the Glens—narrowing, as these glens do, towards the head. But this is negatived by the fact.

6. On more narrowly considering the effect of tidal action, it will readily occur, that the beaches formed by the sea must be materially different from those of a lake, in which there is no movement of the water at the sides, except such as is caused by winds common to both. In the case of the sea, there is not only a vertical rise and fall of water (which, on the west coast of Scotland, is from 8 to 16 feet) twice in the 24 hours, but also a good deal of lateral current alternately in opposite directions. Hence the sea, whilst it will cut into the land more rapidly than a lake, will also spread out more completely the detritus washed down into it. In a lake, on the other hand, which has no movements of water either vertical or lateral, the detritus deposited on the sides of a valley occupied by it, will

be scarcely if at all removed, and will thus form projecting buttresses nearly flat in their upper surfaces, and presenting steep escarpments towards the lake.

Now, applying these two principles of tidal action to the shelves of Lochaber, we seek in vain for any actual indentation into the sides of the hills. The shelves consist entirely of buttresses which stand out from the sides of the mountains; and these buttresses, so far from sloping at an angle little less steep than that of the sides of the mountains (which would be the case with the sea), form flats or terraces which deviate in general very slightly from the horizontal.

7. If the shelves were formed by the action of the sea, they should be most distinct at places where the hill sides had been most exposed.

Thus, on the north and north-west sides of Craig Dhu, and on the west side of Bohuntine, where there must, on Mr DARWIN'S theory, have been an open expanse of ocean, the shelves should have been most distinct. But at these places, the three highest shelves are entirely absent; the fourth alone is visible, though, being the lowest, it must have been less exposed. It is quite anomalous, on the marine theory, that the shelves should not have been formed where the force of waves and of tidal currents must have been greatest, and that they should have been most distinctly formed in the higher and more sheltered parts of Glen Roy.

The hills at the mouth of Glen Roy seem rather to indicate that the highest shelves had not been formed on them,—the very reverse of what might have been anticipated if Mr DARWIN'S views are sound. If they had been formed, they would not have been obliterated, as is manifest from the perfect preservation of shelf 4 on Craig Dhu and Bohuntine.

8. Having stated these objections to the theory of Mr DARWIN, I proceed to consider his objections to the theory, that the shelves were formed by lakes.

These objections resolve entirely into the difficulty of explaining the disappearance of the barriers, which must have dammed back the water in the valleys. But it would be no good reason for rejecting an explanation founded on the existence of barriers, even though we could not very clearly account for the disappearance of them, provided that there is direct and conclusive evidence that such barriers existed. Now, I conceive that there is such evidence furnished by the considerations before referred to.

Let us examine, however, the alleged difficulty of explaining, how the waters could have been dammed up in the valleys to the height of the several shelves.

Shelf 2 is distinctly marked on both sides of Glen Roy, down to a certain point,—and also on both sides of Gln Collarig, down to a certain point. At this period, the water flowed from the east end of Glen Roy into the valley of the Spey. Something must have existed, therefore, in both glens at the points above referred to, to prevent the extension of the shelf westward.

Shelf 3, in both glens, extends a little more to the west than shelf 2. We

have seen that, whilst Glen Glaster is exempt from shelf 2, it is well marked on both sides by shelf 3.

To explain these facts, I assume that there was a blockage of some sort, in Glen Roy, which filled the lower part of the valley up to the level of shelf 2, and which blockage extended a little farther east than the mouth of Glen Glaster. I assume also a similar blockage in Glen Collarig, which filled the lower part of the valley, and as far eastward as the place where shelf 2 stops in that glen. This blockage may have been gravel, clay, or any other detrital matter.

Such is the supposed state of things, whilst the waters stood at shelf 2 in Glen Roy; at which period, it will be remembered, they were discharged to the eastward.

Former writers have assumed, that when the waters sunk from shelf 2, the amount of sinking must have been 82 feet, the distance of shelf 3 below shelf 2; and that this sinking had been one act, caused by an earthquake, or other violent operation, which all at once lowered the barrier by that number of feet. But this is a mistake. MacCulloch takes notice of a shelf faintly marked on Tombran hill, between shelf 2 and shelf 3, though he expresses afterwards some uncertainty about it. In fact, there are two intermediate shelves visible there; and they are also discernible, at precisely the same level on Ben Erin, and also more distinctly near Acharaddy, on the south side of Glen Roy; the one being about 14 feet below shelf 2, and the other about 36 feet lower down.* These two intermediate shelves clearly indicate, that the water which filled the valley, did not all at once sink from shelf 2 to shelf 3. They prove that the water first sunk down 14 feet, and was stationary at this level for some time; that it then sunk down other 36 feet, and continued at this level for some time; and that it again sunk other 32 feet, at which level it remained for a much longer period, till it formed shelf 3.

It is evident, from these facts, that the lowering of the barrier (of whatever material composed) which confined the water in Glen Roy, was a process of a more gradual and ordinary description than what former writers, and especially Mr DAWKIN, suppose. It is plain, also, that the barrier which kept in the waters was less rapidly worn down, when they stood at shelves 2 and 3, than at either of the intermediate levels. We see that at shelves 2 and 3 the waters flowed over rocky ledges, in the one case into Spey valley, in the other case by Glen Glaster. Is it not fair from this to infer, that at the intermediate shelves, the water flowed over a blockage of such a nature as was capable of being more easily worn down and obliterated, such as detrital matter? It is, at all events, obvious, that when

* There are hummocks or knolls of stratified gravel and sand in Glen Glaster, the tops of which are all about 36 feet above shelf 3. It is probable that they were deposited when the lake stood at one or other of the intermediate plateaus last mentioned.

the water sunk 14 feet, the discharge must have ceased at the east end; and that it henceforward would go on at the west end, probably near the mouth of Glen Glaster. At every other place, the rocky mountain sides rise so high, as to preclude the possibility of overflow or attrition.

Keeping these principles in view, let us suppose that the detrital matter which blocked up the lower parts of Glen Roy extended a very little to the east of the mouth of Glen Glaster. How easy it is to suppose that this detritus was scooped away, so as to allow of the recession of the waters westward, and of their flowing round the east jaw of Glen Glaster, and on towards the head of that glen, from which they would descend to Glen Spean? For this purpose, it is not necessary to suppose, that there was any *lowering* of the supposed barrier in level, even by a single foot. All that is required is the scooping or wearing away of the detritus, so as to allow of the extension of the lake a little to the westward;—a few yards would be sufficient. As the discharge at this first sinking, must have been at the west end, it is fair to infer that the wearing away of detritus took place there; and when once a flow of water was established through detrital matter, the process of removal would go on rapidly, so as to allow of repeated sinkings of the lake, till it reached the water shed at the head of Glen Glaster, the rocky nature of which would for a time stop any farther sinking, and thus allow of the formation of shelf 3.

According to the foregoing views, we see how the waters would, by successive steps, sink from shelf 2 to shelf 3, and, after entering Glen Glaster, form a marking on both of its sides. We see, also, that the same removal of detritus which allowed the formation of shelf 3 in that glen, would allow also the extension of it on Bohantine Hill, beyond the point where shelf 2 terminates.

Whilst this process of attrition was going on in Glen Roy, there need have been no contemporaneous change in the blockage of Glen Collarig. But there also, at some time or other, a similar scooping out of detritus must have taken place, to allow of the extension of shelf 3 beyond the point where shelf 2 terminates.

Nor is it difficult to conceive, how this removal of detritus was effected. Thus, in Glen Collarig, there are, on both sides of the glen, burns of considerable size and power (from the steepness of their channels) which flowed into the lake. There are three of them, which now descend in that part of the glen marked by shelves 2 and 3. If the detritus which formed the blockage in the lower part of the valley consisted of the same loose sand and gravel which now abounds there, forming cliffs from 70 to 80 feet high, nothing is more easy or natural than the scooping of it out, by such means.

The same observations apply to the blockage in Glen Roy, which, to prevent the waters when at shelf 2 flowing into Glen Glaster, must have been near the mouth of Glen Collarig, called Gap in the maps, out of which, from the number of streams in it, a considerable current had flowed.

So far with regard to the first depression to shelf 3, at which period I suppose the Collarig blockage to be still existing (scooped out a little towards the west), and the blockage in Glen Roy to have been, by a similar process, removed below the mouth of Glen Glaster. The next well marked shelf is No. 4, which is seen on Craig Dhu and Bohuntine, and on both sides of Glen Collarig, and which infers the necessity of removing the blockage entirely from both Glen Roy and Collarig.

This may have been, as in the case of the previous depression, a gradual operation. There is no improbability whatever in the ultimate removal by rivers and burns, of a blockage of the nature supposed. There flows into Glen Roy, from Bohuntine hill, and at or near the very place where the blockage must have existed, the Tundrun Burn, the sides of which shew mica-slate rocks cut through by it to the depth of about 70 feet, and detrital matter above these rocks cut through to the depth of 130 feet. If, since the drainage of the lake, it has thus cut through and removed blockage to the depth of 200 feet, of which one-third is solid rock, this rivalet must have had nearly equal power to wash away the more superficial blockage which existed at this place previously to that event.

The same observations apply to the detrital matter in Glen Collarig, which could easily be carried away by the numerous mountain torrents flowing into that glen.

The following is the manner in which Mr DARWIN alleges that the two depressions must have taken place, according to the lake theory. He says, that there are two barriers, one in Glen Collarig, and the other in Glen Roy: "Let one of the two barriers, we will say the smaller one in Glen Collarig, give way from the effects of an earthquake, or other cause, the lake will now stand at the level of the middle shelf, the barriers having given way 82 feet vertically. Again let it burst, and this time rather more than 212 feet vertical must be swept away. Let all this have taken place, but still a barrier nearly a mile long and 800 feet in height is left standing across the mouth of the Roy. Must we suppose that each time the barrier in Glen Collarig failed, the one in Glen Roy gave way the same number of feet, through some strange coincidence?" It is plain, from this representation, that Mr DARWIN had not in his view, the more simple and gradual process of removal which I have ventured to suggest. It is not in the least necessary to imagine, that there was any sudden sweeping away of barriers of the magnitude supposed; and which would certainly imply the existence and operation of some stupendous agent; but the effect of which would, as Mr DARWIN truly says, have also probably obliterated the shelves. The process which I have suggested, implies the continuous working of ordinary and natural agents,—agents which are now seen at this very place, producing results similar to those required.

Mr DARWIN says, that the barrier across the Roy must have been 800 feet high. This is on the assumption, that the valley of the Roy was then of its present depth and form. But is there to be no allowance made, for the removal by the

river Roy of detritus from the valley? It is manifest, from many appearances along its sides, that the river Roy has cut down at least 200 feet below what was the original bottom (whether of lake or estuary), formed when the waters stood at shelf 4; so that the height of the supposed barrier to retain the waters at shelf 2 would not exceed 600 feet above the bottom of the valley, and might be much less, if the valley were more filled up. Mr DARWIN considers it probable (p. 58), that the buttresses existing on the sides of Glen Roy indicate, that the valley, upwards from Bridge of Roy, had been filled with detrital matter to the very level of shelf 4; in which case the blockage or barrier requisite to form a lake at the level of shelf 2, would have been only about 300 feet above the bottom of the valley. My belief, however, is, that the whole not only of the lower part of Glen Roy, but also of the district about Unachan, High Bridge, and Fort-William, was blocked up with detrital matter, which, in the course of time was washed away by rivers; and that, when the blockage of Glen Roy was removed, the depressed waters standing at shelf 4 were dammed back by detrital accumulations near Unachan, so as to force a discharge by the Pass of Muckal. This 4th, or lowest shelf, seems to me to stretch much farther to the north, on both sides of the Spean, than former observers have noticed. On the hills flanking the east side, this shelf can be traced to within nearly a mile of Spean Bridge. On the opposite side of the valley, it can be traced to within 6 or 7 miles of Fort-William. The width of the valley where this shelf on both sides ceases to be visible is about 4 miles. Across the mouth of this valley, a little beyond a line joining the extreme visible points of shelf 4, lies the high and elongated hill of Tomtemparsichin, the top of which I found, by the level, to be only 50 or 60 feet below shelf 4; and there is no great difficulty in imagining that the whole of this district, as far as Fort-William, where the enclosing hills are greatly higher, was filled by detritus. There are, even now, detrital remnants of enormous size, of which the well-known Hill of Tomnaharich at Inverness (about 180 feet high and half a mile long), and a hill to the west of it (340 feet high), are specimens indicating the prodigious accumulations once existing in the great glen.

To this point I shall revert. But, in the mean time, taking for granted that such detritus did fill the lower parts of the valleys, it is easy to understand how it should have dammed up the waters into lakes, and how, by a gradual and long-continued process of wearing down, this detrital blockage should have been lowered to the requisite extent.

I have endeavoured to explain the damming back and the depressing of the lakes to their successive levels, without imagining that the level of the sea was then different from what it is at present. If the sea stood at a higher level, then the difficulties of the explanation become less; because the valleys must then have been previously less excavated than they now are, by the operation of rivers. There are good reasons for believing, that since the period of the deposit of the

boulder-clay in Scotland, the sea has stood at least 1000 feet higher on the land than at present. Of course, it must have been after the land rose out of the sea to some extent, that the Lochaber shelves could have been formed by lakes; but the lowest of these might have existed when the sea stood 500 feet above its present level, in which case the depth of detrital matter required to dam up the valleys would be comparatively small.

I have attempted to explain how the valleys of Glen Roy, Glen Collarig, and Glen Spear, were blocked up. There still remains Glen Gluoy, which, as before mentioned, contains two shelves, one of which is about 29 feet above the highest of Glen Roy. Glen Gluoy being unconnected with the other valleys, requires a separate blockage. There would be no great difficulty in imagining the existence of detrital blockage in this glen, at the place where its shelves terminate towards the west, as it is generally, throughout its whole course, exceedingly narrow; and being unconnected with Glen Roy (though MacCulloch states the reverse), its blockage may have been worn down at periods, and in a way, independently of Glen Roy and Glen Collarig.

Before, however, forming a very decided opinion as to the position of the blockage applicable to Glen Gluoy, I should like to examine more particularly than I was able to do, some of the other Glens which open into the Caledonian valley on both sides, with the view of ascertaining whether they contain traces of horizontal shelves about the same height. Mr DARWIN takes notice of one in the valley of Kiffmuir,² about 10 miles to the eastward, and which he says is (by his barometric observations) about 40 feet above the highest shelf in Glen Roy; in which case it would be only 10 or 11 feet above that in Glen Gluoy, a difference quite within the limits of error.

I have observed several places along the Caledonian Canal, where there are traces of one or more horizontal terraces, at a height of from 650 to 690 feet above the sea. From these considerations, I infer the possibility of there having been a blockage which applied not merely to Glen Gluoy, but to other glens opening into the great Caledonian valley; and it would, therefore, be most important, that future observers should turn their attention to the adjoining districts.

My explanation of the Lochaber shelves depends entirely on the accuracy of the supposition, that the valleys were, in the lower parts of them, filled up with detrital matter, capable of being gradually worn down and washed away. This supposition is not only not improbable on general principles, but is verified to a great extent by the remains of such detrital matter at and above the heights required for it. Thus, in Glen Collarig, there are to be seen, near the east end,

² It is to be regretted that Mr Darwin, when he visited Lochaber, was not provided with a spirit-level. His statement as to the horizontality of this shelf at Kiffmuir, depends entirely on casual inspection, and barometric measurements.

and within about half a mile of the place where the blockage must have existed, enormous heaps of boulder-clay, gravel, and sand. These detrital deposits must have existed in Glen Collarig before the shelves were formed, because shelves 2 and 3 are seen distinctly indented upon these deposits; and I was particularly struck with the fact, that these deposits reach to a height of more than 100 feet above shelf 2. Here is proof, that in Glen Collarig, before the formation of the lake which filled it, there was detrital matter of sufficient depth and consistency to have retained water at the required height. At the place where shelf 2 terminates in this glen, the valley, even at present, is only about 250 feet deep, and 300 yards wide, so that the depth of detrital matter does not exceed the limits of probability—nay, is exemplified by the occurrence of much larger accumulations of detritus in all parts of the Highlands.

It is here proper to explain, that there are in these valleys, as elsewhere in Scotland, two distinct sorts of superficial deposits,—the one consisting of the well-known boulder-clay, and the other of ordinary gravel and sand. This boulder-clay exhibits the same general characters, which it commonly possesses elsewhere; it is unstratified, exceedingly obdurate, of a dark-bluish colour, and filled with water-worn boulders. This boulder-clay I found at the following places:—Spean Bridge, where it is covered by sand; Bohuntine Hill, where it is covered with laminated clay, sloping to the centre of the valley, and about 250 feet below shelf 4; Bohina, on the south side of Glen Roy; Inverlair Bridge, near Loch Laggan; Glen Glaster (on the west side of the valley), from 50 to 80 feet above shelf 3; Glen Collarig (near the gap), where it rises above shelf 2; Glen Glosy, as seen at the watershed between it and Glen Roy, and as a level with shelf 1. The deposit occurs also at Clonchan, at the river Roy, where the mica-slate rocks, through which the river now runs, are covered immediately by boulder-clay,—the boulder-clay being here covered by deposits of irregularly stratified beds of gravel and sand, from 150 to 300 feet thick. At this place, I observed among the boulders in the hill, granites (with red and grey varieties), old conglomerate, and red porphyry,—rocks, all of which must have come from a distance.

From the fact that this boulder-clay occupies alike the highest and lowest parts of the glens; and, more especially, that in several places it is seen distinctly covered over by laminated clay as well as by stratified gravel and sand, it may be inferred that the boulder-clay, with its imbedded blocks, was deposited, certainly not after the drainage of the lakes, but either before the valleys were occupied with water, or during that period.

In regard to gravel and sand, I do not remember having, in Glen Roy or its contiguous valleys, observed any considerable beds of it, so high up as the boulder-clay. But at lower levels, there are everywhere enormous cliffs of it to be seen, several of which I measured, and found to exceed 180 feet in height. These cliffs are formed out of the ancient bottom of the lake or estuary which filled the valleys, and are

composed of materials washed down from higher levels. The adjoining mountains of the district afford ample evidence, that gravel as well as boulder-clay had been, by some cause or other, brought and deposited over all this country, filling the valleys to heights exceeding the highest of the Glen Roy shelves. Thus, on the turnpike road between Tyndrum and Invercurnan, near the summit level between the two valleys, which I estimated to be about 1080 feet above the sea, there is great abundance of sand and gravel. On the Black Mount, about 4 miles north of Invercurnan, and at a height of 1300 feet above the sea, there is an immense accumulation of gravel and boulders, particularly on the south side of the summit. In the high ground north of Dalwhinnie, which I estimated at 1200 feet above the sea, there are great heaps of gravel, forming mounds and ridges. These facts, taken in connection with the undoubted fact, that detrital matter has been spread over the greater part of Scotland, to a height of at least 1500 feet above the sea, pretty clearly indicate, that detrital matter not only may have been, but actually was spread over the Lochaber district, and filled its several valleys, to the height of at least the highest of the Glen Roy shelves, thus affording ample blockage for its lakes.

I may mention that there are, in this part of the Highlands, several lakes of small size, at very high levels, the existence of which renders the lake theory of the Glen Roy shelves less improbable than to some it may appear. Thus, at the well-known pass of Rest-and-be-Thankful, there is a small lake, which is about 800 feet above the sea, and there are traces of its having stood formerly from 40 to 50 feet higher. To the south and west of Loch Treig about 3 miles, there are two considerable lakes, one called the Lake of Corry, and the other called Benoffap, which appear, from the accounts received of them, to be about 1200 to 1300 feet above the sea. There are several also on the Black Mount, at about the same high level.

Before concluding what I have to say regarding the parallel roads of Lochaber, I may briefly notice the theory, that the lakes which filled them may have been confined by glaciers, or by the moraines of glaciers.

This was one of the districts which, in the opinion of AGASSIZ and BUCKLAND, afforded undeniable proofs of the existence of glaciers. The former published a paper* on the subject, in which he says: "When I visited the parallel roads of Glen Roy with Dr BUCKLAND, we were convinced that the glacial theory alone satisfies all the exigencies of the phenomenon; and as this locality is the best known, I may limit myself to this example for the explanation of all others."

M. AGASSIZ, in the paper now alluded to, explains the grounds on which his theory rests; and it is accompanied by a plan of the locality.

It appears to me, (1.) That the facts on which M. AGASSIZ rests his theory

* Ed. Phil. Journal, vol. xxxii., p. 252.

are incorrect. (2.) That, assuming as true the facts stated by him, they still afford no evidence that glaciers existed in the Lochaber valleys.

(1.) There are three main facts relied on by M. AGASSIZ. He states, *First*, That in Glen Roy, and in that part of Glen Spean, between Bridge of Roy and Loch Treig, there are 3 shelves visible; *Secondly*, That these shelves all terminate, on both sides of the valley at or near the Bridge of Roy; *Third*, That the bottom of Glen Spean, in front of Loch Treig, is not only polished with that polish characteristic of glaciers, but is, moreover, scratched transversely,—that is to say, at right angles to the direction of the valley, by a cause which evidently proceeded from Loch Treig.

To explain these appearances, it is suggested, that “the supposition of a great glacier descending from Ben Nevis, and shutting up the valley of the Spean, by resting on Moeldhu, which is opposite, combined with the influence of a glacier from Loch Treig, and which would bar the valley a second time at that height, would explain all the facts.”

These facts, for an explanation of which this theory was invented, appear to me not to have been accurately observed. In the first place, the three shelves do not occupy, as M. AGASSIZ asserts, “all the sinuosities of the lower part of Glen Spean, and of the whole of Glen Roy.” It is only the lowest of the three shelves, which occurs in Glen Spean and in the lower part of Glen Roy. The two uppermost shelves stop short of the mouth of Glen Roy, by about 2 miles; so that, if the Lake in Glen Roy was dammed back by a terminal moraine, that moraine could not have rested on Moeldhu, at the foot of Glen Roy; but must have been pushed up that valley, before the Ben Nevis glacier, 2 miles farther,—an operation which the levels, distance, and direction of the valley would have rendered impossible.

In the second place, the shelves do not, as M. AGASSIZ says, “terminate at the same point,”—viz., at Moeldhu, where he supposes the terminal moraine of the Nevis glacier to have been. The two uppermost shelves (as just stated) do not come within two miles of this point; and the lowermost shelf, instead of terminating there, runs, as formerly explained, several miles northwards, on both sides of the valley, towards Unachan, where they are 4 miles apart. It is scarcely necessary to say, that a moraine in this low district, which is not connected with any Ben Nevis valley, and considering its required height and length, is inconceivable.

In the third place, as to the existence of transverse scratches on the rocks in Glen Spean, which are said to indicate the movement of some body from Loch Treig, I could see no such scratches, though I twice surveyed the ground, and narrowly inspected the rocks, especially at the outlet from Loch Treig. Indeed, the supposition that any glacier flowed out of Loch Treig seems to be almost excluded by the fact, that a shelf, perfectly horizontal, exists on both sides of the

narrow outlet from Loch Treig, and continuously into Glen Spean. Such a shelf could not have been formed, and would have been obliterated by any glacier moving out of Loch Treig.

(2.) But assuming all these facts to be as M. AGASSIN states them, do they present unequivocal proofs of the movement of glaciers, and the formation of moraines? Scratches on polished rocks, may be made by various causes; and if a moraine existed on Moeldhu, surely some trace of it, or of the great blocks which generally accompany moraines, would have been particularly observable there;—whereas there is scarcely a block or a patch of gravel to be seen in that part of the valley.

Farther, I would observe, that the valley supposed to have been the birth-place of the glacier, which produced this Moeldhu Moraine, is about two miles distant from Moeldhu, with an undulating country between them, which is most unlikely to have formed the channel or bed of a glacier. Dr BUCKLAND and M. AGASSIN speak of this glen, as connected with Ben Nevis. But here, again, there is apparently some mistake. The valley in question is Larich Leachich, and runs up, not in a NW. direction towards Ben Nevis, but in a SW. direction towards the head of Loch Treig. It is an extremely short glen, and rises to no great height.

Finally, supposing, that in spite of all these objections, it were allowed that a glacier had moved down this little valley, and across the very uneven country to Moeldhu, so as to block up Glen Roy and Glen Spean, it would still remain to explain the blockage of Glen-Gloey, which, by no possibility, could be accounted for by a moraine at or near Moeldhu.

That there are certain appearances in the valleys of Lochaber, which must have been produced by attrition of some kind, I am free to admit. Water, accompanied by gravel and other detritus, appears, however, to have been the agent, and not ice. At the Monessie Falls, the valley is compressed to a narrow gorge, and the rocks forming the east side, present evident marks of attrition on a large scale, the rough faces of the rock being all down the valley. The rocks are here covered by sand and gravel, which indicate the flowing of water and of drift at that height, when these rocks were worn down. In like manner, at the outlet of Loch Treig, there are immense expanses of rock, all smoothed and rounded on the sides facing the SW. or WSW. by compass.* These smoothed rock-faces prevail to a height of about 780 feet above the lake, and 1660 feet above the sea, above which level they are no longer visible. There are many boulders lying on these smoothed surfaces, all of rounded forms. That these boulders have come from

* The general line or axis of the lake is north and south by compass, the upper part being towards the south, so that the motion of a glacier down this valley would have smoothed all the south faces of the rocks. It is also important to remark, that, on the west side of the lake, the rocks facing the lake are, as compared with those on the other side, exceedingly rough, showing still more clearly that the smoothing agent had crossed the valley of Loch Treig, in a direction not parallel with its longer axis, but obliquely to it.

the west, is evident from the nature of them; several of a pink coloured felspar, having been traced by me to a dyke of the same peculiar rock a few hundred yards to the west, from which they had evidently been derived. Another circumstance proved this still more strikingly. In one place, a few hundred feet above Loch Treig, I observed a series of rocky knolls, in an east and west line. The parts of these knolls which were smoothed and worn down were uniformly to the west, whilst their rough faces were all to the east, thus—



It was clear, on an inspection of these knolls, that they had been worn down on their west sides; and the smoothed sides *c* were so close to the knolls respectively to the west of them, that nothing except some fluid, charged, it may have been, with drift, could have possibly reached and acted on them.

This last point was still more palpable, in several places, where there were narrow smooth-sided troughs, more or less steep, on the sides of hills. These troughs had apparently been natural fissures in the rocks, which had been smoothed by the long-continued action of water; for the notion that ice could have entered and rubbed them, was entirely precluded by their narrowness, situation, direction, and other circumstances.

M. ADAMSSON, in the paper before alluded to, says that he will never forget the impression he experienced "at the sight of the terraced mounds of blocks which occur at the mouth of the valley of Loch Treig, where it joins Glen Spean. It seemed to me (he adds) as if I were looking at the numerous moraines of the neighbourhood of Tines, in the valley of Chamounix." These terraces of blocks, thus likened to moraines, are, I presume, the accumulations of blocks on the lowermost horizontal shelf, which is very conspicuous at the entrance to Loch Treig on both sides of the valley. On this shelf there are multitudes of blocks, just as in many other parts of the valleys, where this shelf and the others occur. But this fact is perfectly consistent with the theory, that these shelves were formed by water, and, indeed, can be explained on no other, when it is considered that they form at Loch Treig, as at every other place, a line absolutely horizontal,—a quality which, I presume, no moraine ever possesses.

The only place where I observed an accumulation of blocks, at all resembling a moraine, is on the east side of Glen Spean, near a place called the Rough Burn.

about three or four miles to the north of Loch Laggan. The accumulation is enormous. Blocks are piled over each other, to such a height as to render the general surface of the moor, over a wide extent, quite undistinguishable. This accumulation occurs not at the mouth of any valley. On the contrary, the hills near these blocks on the east side, are not much furrowed even by mountain torrents, and present a somewhat steep and high wall face to the west. On looking round for any possible explanation of the occurrence in this spot of so unusual a quantity of boulders, consisting almost entirely of grey granites, whilst the rocks on which they lie are different, I could not help noticing that the valley on the opposite or west side presented an opening or depression, though at the distance of 2 miles. This opening is the outlet of Loch Treig, and bearing about WSW. by compass. The appearance of the locality at once suggested the probability that the blocks had in some way issued through this opening, and had been transported across the valley to their present situation, where their farther progress was arrested by the lofty hills forming here the east side of Glen Spean.

I have already stated reasons for thinking that no glacier issued from Loch Treig. The only alternative seems to be the agency of water.

I proceed now to shew that the lake theory of the Lochaber shelves, and the principles on which I have endeavoured to account for the formation of lakes, and the eventual depression and drainage of them, are not inconsistent with any established geological truths,—but, on the contrary, receive support from collateral considerations.

1. The first circumstance which I shall notice, is the occurrence of *Parallel Roads* in other valleys similar to those of Lochaber, the formation of which can be attributed to no other cause than lakes.

I have the less hesitation in availing myself of this argument, when I find Mr DARWIN adverting to traces of shelves at Kilfinnin, and in the valley of the Spey, in support of his theory.

But if Mr DARWIN'S views are sound, traces of shelves should not be confined to the two localities just mentioned; they should be visible in other parts of the country of equal height as the Lochaber mountains.

On the other hand, if it should appear that there are in many valleys, distinct beach lines, all horizontal, and presenting no uniformity of height above the sea, the argument against a sea theory will be strengthened, whilst a strong analogy will arise to favour the lake theory,—if these beach lines, precisely similar in all essential features to those of Lochaber, can, from their inland situation, and other circumstances, be clearly shown to have been produced by the waters of lakes.

I proceed therefore to mention a few localities out of many, where phenomena similar to those of Glen Roy are observable.

(1.) At Inverourman (about 40 miles SW. of Lochaber) there is a lake called

Loch Tulla, about 3 miles in length, and 1 in breadth. A stream enters from its east and west ends. Its surplus waters are discharged from its south side, by the river Urchay.

Two years ago, I discovered all round this lake indications of three levels at which its waters had stood, the lowest being about 189½ feet, the second 277 feet, and the highest 474 feet, above their present level.* Loch Tulla I roughly estimated at 540 feet above the sea. This lake, therefore, extending originally to about 6 miles in length and half a mile in breadth, had sunk 197 feet,—at which level it had stood long enough to form the second shelf; it next sunk 83½ feet,—when the third shelf was formed; after which it sunk 183½ feet,—viz., to the present level of the lake.

It is unnecessary for me to enter into the proofs, that what I am now describing are really beach lines. Their perfect horizontality, which I ascertained by a spirit-level, looking at them from 12 or 15 different places along the banks of the lake,—their general conformity in sweeping round headlands, and retiring into valleys or burn-courses,—and the extent of flat surface at the levels of the different shelves, afford convincing and irrefragable proofs.

The difficulty here, as in other similar cases, is to discover, what could have dammed up the lake so much above its present level. The blockage, whatever it was, must have existed somewhere in the valley, through which the river Urchay flows. The country, on all other sides of Loch Tulla, rises much higher than 500 feet above its present level. The two lowest shelves are traceable for some distance down the valley of the Urchay,—the middle shelf for about half a mile, and the lowest considerably farther. My notion is, that this valley had been formerly filled with a great accumulation of gravel and diluvial debris, which was gradually cut away and lowered by the stream which issued from the loch. Accordingly, there exist still, at and near Urchay Bridge, great heaps of unstratified gravel, which clearly present only a remnant of what must have formerly existed. The valley at this place, is a quarter of a mile wide; and its sides rise far above the required level.

(B) In the valley, at the head of which Tyndrum is situated, there are very manifest indications of the beaches of an ancient lake, although the valley is now occupied by only an insignificant stream. At Strathfillan church, the lowest terrace is about 50 or 60 feet above the stream, and may be traced continuously for at least a mile down the valley. The stream has cut through this old lake bottom, exhibiting beds of gravel, sand, and clay, which have been deposited and arranged by the water. About 237 feet above this flat, there are, on the sides of the hills on both sides of the valley, traces of a horizontal shelf, which can be distinctly followed with the spirit-level from above Tyndrum village, down the valley by Auchroch farm-houses, Enich farm-houses, and as far as Crianlarich

* These measurements were made by a mountain barometer, checked by the spirit-level.

1014
57
127
60
556

toll. At several places, boulders appear to have accumulated on this higher shelf. Tyndrum is about 740 feet above the sea.

(3.) Along the margin of Loch Awe, and particularly near Dalnally, there is a flat or terrace about 40 feet above the present level of the lake; and which manifestly indicates a subsidence of its waters to that depth.

(4.) Along the margin of Loch Lubnaig, in like manner, there is a flat or terrace about 40 feet above the lake, and which is very visible on both sides. Here as well as in the former case, the flat runs back from near the margin of the lake to the mountains forming one side of the valley; and the steep sides of which, contrast most significantly with the almost horizontal flatness of the ancient and exposed bottom.

At Loch Lubnaig, the flat can be traced for a considerable way on both sides of the valley, beyond the point where the lake now discharges itself, and, indeed, almost as far as Leny. At this place, as well as at Callendar, there exist indications of enormous quantities of gravel, which, before being cut down and carried away by rivers, afforded ample means of blocking up the waters of Loch Lubnaig to a higher level. The quantity of gravel which formerly existed hereabouts, may be inferred from the existence of the following remnants.

About $\frac{1}{2}$ mile west of Callendar, there is a ridge of gravel and sand about 100 yards long, and from 40 to 50 feet high. Near it, there is a conical mound of the same materials, and about the same height, bearing a thriving plantation. The ridge of gravel to the east of Callendar, designated in guide-books as the Roman Camp, is merely a remnant of the ancient gravel-bed with which the whole valley was filled; and when it contained a lake, of which there are abundant indications, it is probable, that, when Loch Lubnaig stood 40 feet above its present level, its waters were discharged into a lower lake, of which the eastern margin may be seen near the Lodge of Gart-House. Ultimately the gravel heaps which held in this Callendar lake on the east, had been cut through, so as to allow of its drainage; and, accordingly, there are, on each side of the river Toth at this place, gravel banks and cliffs from 70 to 80 feet high.

After the Callendar lake was drained, the waters which flowed out of Loch Lubnaig would acquire fresh cutting power, and would rapidly cut away the barrier which dammed back the lake to the higher level before referred to.

Callendar is about 270 feet above the sea.

(5.) In the valley in which the town of Huntly stands, there are two terraces, the one about 32 feet above the other, which are very clearly the beaches of a lake, which has sunk from the one to the other, and latterly been drained off.

(6.) A few miles south of Inverury, there are distinct traces of a lake which formerly filled the valley. The burgh of Kintore has been built in the ancient bottom of the lake. There are two well-marked beach-lines round the whole valley;

the one about 78 feet, and the other 50 feet, above the channel of the united streams of Don and Urie, which flow through the centre of the valley. The ancient bottom of the lake has been cut up by rivulets at the sides of the valley into separate fragments, some of them of so unusual a form as to have suggested a notion that they are artificial; and, accordingly, in the guide-books, and even in the recent statistical accounts of the parish, they are so described. Two of these alleged remains of antiquity are known by the names of Bass and Kenin Hillock; and are variously conjectured to have been formed for sepulchral or judicial purposes. A similar mistake has been made with the hills of Dunipace, near Falkirk, which are represented by historians as formed to celebrate and record a peace between the Romans and the natives of Scotland. They are detrital remnants fashioned into conical shapes by the action of streams.

(7.) In the valley of the Leader (Berwickshire), there will be found terraces on the hill sides, which clearly show the action of water. Three very distinct markings of this nature are traceable near Dodds' Mill, at Hounslow, at Carfrae Mill, and at Annfield near Channellkirk. The terraces at these different places, judging by the sympiesometer, seem to be all very nearly on a level; and if, on a more minute survey, they really prove to be so, it would follow, that the whole of Lauderdale had formerly been one vast lake, with a blockage at or near Chappel. The height of these shelves is about 800 feet above the sea.

It is scarcely necessary to advert to the inland situation, and other circumstances characteristic of the various beach-lines now mentioned, to show that they could not have been formed by the sea, but must have been produced by lakes which filled the valleys, and which sunk at different periods,—in most cases, disappearing altogether.

If, then, the existence of lake-beaches be so common in the valleys of Scotland, there will be the less hesitation in ascribing the Lochaber shelves to the same cause,—established as that cause has been separately by local evidence.

That the occurrence of lake-beaches in the valleys of Scotland should be frequent, is only what every geologist must be prepared to expect, who considers the proofs which may be adduced, of the gradual emergence of the land out of the sea. Some of these proofs, in so far as afforded by Scotland, I shall immediately notice; but assuming that Scotland was, to the depth of 1300 feet or more, submerged beneath the waters of the ocean,—as it rose out, there would be lakes in every inland hollow, each, of course, having its river to carry off to the sea, the rain falling on its surface and that of the adjoining mountains. The stream thus issuing, would gradually wear down the detritus which formed a barrier at one end of the lake; and the cutting power of the stream would be gradually increased, as the elevation of the land proceeded; so that in most cases the blockage of lakes would, in the course of time, be extensively undermined

and worn down, and sudden depressions of lakes would take place, leaving marks of horizontal shelves along the sides of valleys.

The progress of these important changes is indicated, in many parts of the country, by the existence of haughs or river-flats, far above the present channels of the streams, and which evidently had been formed when they flowed at a much higher level.

Thus, from Perth up to Loch Tay, a number of isolated flats or terraces occur, forming a pretty uniform level, rising gently inland, and at a rate rather faster than the slope of the river. Near Perth, these old haughs are from 90 to 100 feet, and at Dunkeld about 110 feet, above the river. This old haugh at Dunkeld may be traced on both sides of the valley, — Dr Fisher's house being on it at the east side, and Claypotts farm-house on it at the west side. It may even be traced a considerable distance up both sides of the Braan, where it slopes a little to the eastward.

There is a low haugh at Dunkeld which is only about 20 feet above the present bed of the river, and is, therefore, quite distinct from the higher terrace above described. The ground is now cultivated and enclosed; so I suppose that the floods never rise to a level with it now.

On the Tweed, in like manner, the remains of ancient haughs can be traced in many part of its course. About half a mile above Berwick Bridge, one may be seen on the south side, from 30 to 32 feet above the sea. At Gainlaw, it is 44 feet; opposite to Finchie, it is 55 or 56 feet; opposite to Paxton, it is 58 feet; at Norham, it is 63 feet above the sea.

At New Burray (in the parish of Blairgowrie) I observed an extensive flat, or ancient haugh, with its cliff or bank about 60 feet above the River Ercht.

On the Isla, above Airdy Castle, there is haugh land, on both sides, about 50 feet above the present level of the river.

On the River Garry, about 3½ miles north of Blair, there are on the east side two terraces, the one about 30 and the other about 50 feet above the river; but whether they are the remains of ancient haughs, or the beaches of a lake, it is difficult to determine.

(What follows does not appear in the published Transactions of the Royal Society of Edinburgh, but is printed by the Author for private circulation.)

2. I proceed now to adduce proofs, that the whole of Scotland, to the depth of at least 1200 feet, has been recently immersed in the ocean, and for a very long period. It will be found that this part of the subject, though opening out views of a very general nature, also throws light on the origin of the Lochaber shelves, and suggests farther reasons for adopting the lake theory.

The evidence of a general submergence of the land beneath the waters of the ocean, may be classed under three heads: *First*, There are, on dry land, at various heights above the present sea-level, the remains of animals of existing species, which must have inhabited the ocean, and been left by the receding waters in the situations where they are now found. *Second*, There are, at great heights above the sea, superficial deposits, which, from their extent, internal arrangement, and component parts, could have been formed only under waters of considerable depth. *Third*, There are indentations on the land (indicated by lines of cliff), and extensive flats or terraces, at high levels, which could have been produced by no other cause than the waters of the ocean at these levels.

Under each of these heads, I shall classify the proofs which I have now to offer.

The following are various localities where *sea-shells* occur above high-water mark:—

(1.) On the farm of Drip, 4 miles west of Stirling, I found, at a height of about 12 feet above high-water mark, and a mile or more from the point at which in the River Forth the influence of the tide is felt, an extensive bed of *Cardium edule*. Both valves were almost always entire, and closed. The individuals were of all ages. I found also in other beds—equally regularly disposed,—great numbers of *Tellina edicula*, *Mytilus edulis*, and *Listera asperans*; they were in finely laminated greyish-coloured clay.

(2.) On Raploch farm, about 2 miles west of Stirling, there is a sandstone quarry, the strata of which are covered by a bed of finely laminated clay about 5 feet thick. This clay-bed contains a number of very delicate bivalves, a species of *Tellina*. They are about 12 feet above high-water mark.

(3.) On the farm of Bandoth, 4 miles east of Stirling, there run through all the fields of that flat district beds of all the shells. Most of these shells were perfectly entire, with both valves closed. They are in a deposit of mud or compacted clay, which fills the shells; and frequently there is a yellow or orange-coloured matter covering the inside of the shell, apparently derived from the decay of the animal. The bed is 10 feet above high-water mark. It is so extensive, and so nearly horizontal, that it affords to the drainers a guide in the cutting of drains, as I learned from a labourer, who shewed me the bed in a drain which he was in the act of cutting.

(4.) At several places near where the River Avon enters the low cause land, and on both sides of the river, there is an extensive deposit of sea-shells, consisting of *Ostrea edulis*, *Cardium edule*, *Littorina rudis*, *L. Neritoides*, &c., most of which are in a broken state, and mixed with gravel, including considerable blocks. They form a fringe which varies in height from 30 to 40 feet above high-water mark, and which extends for about a mile continuously along the bank skirting the cause flat on the south. In a perfect or unbroken state these shells and others, all of which are littoral, form a bed in this cause flat, at a height of from 3 to 14 feet above high-water in Reddock's farm,* Bell's Dyke, Airth House, Kerse House, &c.

(5.) Along the shore from Granton Quarry to near Portobello, a bed of broken shells, consisting of *Ostrea edulis*, *Trochus cinerarius*, *Modiola subtruncata*, *Cardium edule*, *C. echinatum*, and other marine shells, at a height above high-water mark of from 13 to 21 feet.

(6.) At Joppa, and at a height of from 2½ to 3 feet above high-water mark, a stratum of fire-clay, which was excavated for working, two years ago, was found extensively perforated by *Pholus crispata*, which exists now in the Frith, but is never known to live higher than half tide. These borings indicate, therefore, a change of level to the extent of 9 or 10 feet at least. Specimens of this perforated rock have been lodged in the Museum of the Royal Society.

(7.) At Newbidding (situated between Inveresk and Musselburgh), in the fields east of Linkfield, at Ravensburgh, Proctopans, and Seton, there is a layer of broken sea-shells, mixed with sand, and forming a bed varying in height from 7 to 17 feet above high-water. The shells at Seton consist principally of *Ostrea*, *Purpura lapillus*, *Cardium echinatum*, *Modiola truncata*, *Murex erinaceus*, *Succinea undatata*, and *Pecten opercularis*, covered with *Balanus balanoides* and *Serpula trigonata*.

(8.) In the district of Aberlady and Dirleton there are some remarkable marine deposits.

In the flat grounds the shells (chiefly cockles) are so abundant, that they have evidently suggested the name of the *Cockle* farm, the *Cockle* mill, and the *Cockle* Burn. I examined a bed consisting of *Solen axis*, whelks, cockles, limpets, &c., which is about 25 feet above high-water mark, and about a mile distant from the sea. The cockles generally have both valves attached. They are in a clay bed.

On examining a quarry near Dirleton, which is about 125 feet above the sea, and 2 miles distant from it, I found a large quantity of *Patella vulgata* and *Littorina littorea*. They are lying on a bed of sand, which has evidently been undisturbed. Specimens are in the Society's Museum.

* The bed at this place is 3 feet thick, and consists chiefly of oysters and mussels, with both valves attached.

(8.) At Cabsraig, about four miles south of Dunbar, the limestone is extensively worked adjoining the shore. It is there covered by a layer of limestone blocks, most of which are perforated by *Sarcinea rugosa*, and at a height of 14 feet above high-water mark. Specimens have been lodged in the Royal Society's Museum.

At Skateraw, on the north side of the bay, there are, adjoining the shore, horizontal beds of shale, over which, and to a height of about 13 feet above high-water mark, there is a layer of boulders and gravel. The limestone boulders are all perforated with the *Sarcinea*. Many of the shells I found in the holes. In some of the holes, *Serpis* occurred. In another part of the same bay, I found boulders of sandstone lying over the limestone rocks, and at a height of 13 feet above high-water mark, perforated with the *Sarcinea*, and having *Sepet* shells adhering to them.

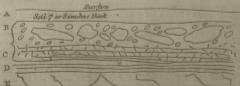
(10.) On the north side of the Frith of Forth, I have, in like manner, traced elevated beds of sea-shells at the following places:—

About a mile west of Alloa, I found a bed of oyster-shells about 5 or 6 feet above high-water mark.

Between that place and Kincardine, there is a continuous bed of oysters, mussels, whelks, cockles, besides the *Tellina* and *Listera* before referred to. At many places I found all the bivalves entire, and frequently containing in their interior surfaces a yellow colouring matter. The bed is, where I examined it, from 4 to 7 feet above high-water mark.

It is not unimportant to observe, that at several places near Alloa, the bed of fine clay in which these marine shells prevail, is generally covered by a layer of gravel, and, in some places, by large boulders many tons in weight. At one place, I noticed that the boulders had been apparently forced into the subjacent clay bed, and had not merely sunk by their own weight.

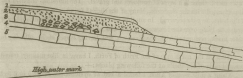
This arrangement is particularly well seen in an old quarry behind a school-house, situated near West-Field Craig.



BC is a deposit of 3 feet in thickness, the lower part consisting of small shells, chiefly whelks, in clay-sand and fine gravel. The upper part consists of boulders

and blocks of porphyry, sandstone, and coal. D is a bed of laminated clay. E is a stratum of sandstone.

(11.) Proceeding eastward, the next place which I shall notice, is half a mile to the east of St Colme Lodge, between Aberdour and Dalgetty Church, where, at a height of 62 feet above high-water mark, I found in the cleft of a sandstone rock a confused heap of oysters, lempits, and whelks. The following section indicates the situation of this deposit, and the mode of its arrangement.



No. 1 is the surface soil.

No. 2 a layer of fine gravel, as small as peas and beans, about 14 inches thick.

No. 3 and 5, strata of sandstone, rising at WNW. at 10°, portions of which have been removed as shown in the figure. In that part there is a collection of sandstone and greenstone blocks, with oysters, whelks, and lempits. The oysters are covered with barnacles, and are pierced with small holes, evidently the work of a borer.

No. 4 is a stratum of light blue clay.

There are many other places, as at Leven, Elie, Buckhaven, and Largo, where I have examined a bed of sea-shells, existing at a level of from 12 to 13 feet above high-water mark,—but which need not be particularly described.

(12.) To this catalogue of localities in the Frith of Forth I may add one or two on the south and west coasts of Scotland, to shew that similar deposits are probably universal.

Near Annan I found a bed of sea-mussels, in laminated clay, about 7 feet above high-water mark.

At the head of Loch Moydart, as I am informed by Mr ROBERTSON, the proprietor, a bed of oyster-shells exists, at the height of 12 or 14 feet above high-water mark. At the same place, he states that there is a bed of shelly sand, about 50 feet above the sea, which is occasionally used for manuring the land.

I observe, in a recent number of the Geological Society's Proceedings, that on the west coast of Ross-shire, a bed of coral and sea-shells, 2 or 3 feet thick, has been found at a height from 50 to 60 feet above the sea.

There are two spots between Eyemouth and Coldingham, from 300 to 300

feet above the sea, and three-quarters of a mile distant from it, where (as I have been assured by the tenant of the ground) sea-shells in great abundance have been found.*

Now, in regard to these shelly deposits, some of them, much more unequivocally than others, bespeak the permanent submergence of the present dry land. I allude to those in which the shells are found entire and unbroken, and embedded in finely laminated clay. Whatever may be thought of the broken shells, it is manifest, that the fragile and delicate shells before referred to, which have both valves entire, could not have been preserved in that state, had they been thrown up into their present position (as maintained by an experienced member of this Society) by storms. The perfect preservation of the shells, and even to some extent of the animal itself, clearly betokened that they lived and died at the places where they are now found. The same conclusion is arrived at on a consideration of the clay beds in which these shells occur, consisting of thin horizontal laminae, being the sediment of unquestionably still and deep waters, certainly not of a stormy sea.

With regard to the deposits of broken shells, and which are generally found at a higher level, they are as clearly indicative of a sea-beach, as the unbroken shells are of a sea-bottom. The composition of the bed, consisting of shells of various kinds, broken and irregularly disposed, of gravel evidently water-worn, and of sand; the existence of an almost continuous line of these shells, fringing the coast at pretty nearly the same level, and the slope of the bed uniformly seaward, all combine to indicate a true sea-beach, formed by the permanent action of the sea and its tides at that level. It is quite impossible to explain even this deposit of broken

* One of these places is Hally-down. The shells (limpets and whelks) were lying on the surface of a trap rock, at its west and exposed side. Mr FURAN, the tenant, told me, that in quarrying the rock, he found the shells among the gravel above the rock, and of which I saw a bed about 4 or 7 feet thick, consisting chiefly of trap pebbles. He had seen, he said, as many shells as would have half-filled a cart.

The other place is on Whitecross farm, on which also a trap-quarry was opened some years ago. It was stated to me, that a crevice was found in the rock, about 3 feet below the surface, large enough to admit a person. In this crevice, limpets were got in such abundance as would have filled a wheelbarrow. It was stated, that no sand or gravel had been found associated with the shells,—a fact quite consistent with the exposed and rocky character of the coast as it now exists.

I may here mention, that on the south bank of the Whitadder, opposite to Edington Mill (parish of Hutton, and county of Berwick), a large quantity of limpets and whelks was pointed out to me by the Rev. Mr WILSON. They occur in clay; but the exact nature of this deposit cannot be made out, on account of a slip in the bank. This spot is about 7 miles from the sea, and at a height of about 120 feet above its level. I feel considerable doubt, however, in considering this a natural deposit, as some rusty nails were discovered by Mr WILSON and me among the rubbish of clay. On the other hand, we were unable to explain how such an accumulation of shells could have been formed by human agency.

shells, on the supposition that it was formed when the sea was at its present level, and that the materials composing it were thrown up by storms. In the first place, it is difficult to conceive that storms would form a deposit so continuous, and nearly uniform in height, along the coast. In the second place, the great height at which, in some places, the shells have been found, and their distance from the sea, also negative the theory.

On these grounds, it appears to me that the deposits of marine shells very clearly indicate a change in the relative levels of sea and land.

Similar evidence is afforded by the discovery of *fish bones* at considerable heights above the sea. On this point, I need only refer to the discovery of whale bones in Ross-shire, 3 miles from the sea, and 12 feet above it; in Stirlingshire, at Dunmore, about a mile from the sea, and at a height of about 20 feet; at Blair-Drummond, Airthrey, and Grangemouth,—the first of these places 10 or 12 miles distant from the sea, and at a height of from 20 to 25 feet above it.

Near Falkirk, there were found, many years ago, in a bed of sand about 90 feet above the sea, and 5 or 6 miles distant from it, the bones of a full-grown seal, and associated with the spout or razor shell. The facts here mentioned will be found noticed in the Transactions of the Wernerian Society.

These facts most undeniably attest the permanent submergence of the present dry land beneath the waters of the ocean.

The *second class of proofs* relates to the existence of *sand, gravel, and clay*, so disposed as to shew that they must have been deposited when the strata covered by them formed the bottom of a deep sea.

It must be obvious, that extensive beds of sand, such as those so familiar to most of us, situated between Edinburgh and the sea, have been deposited in a body of water of considerable extent and depth. It is important to reflect on the circumstances and conditions which favour or admit of the deposition of mere sand. Were this part of the earth's surface now to be elevated so as to expose the present bed of the German Ocean, the accumulations of coarse gravel, including great blocks of stone, would probably be found near our present shore; at a greater distance and depth, the gravel would become finer, and at length banks of sand, and, beyond them, flats of mud would be met with. The debris of the land brought down by rivers, is acted on by the tides and currents, so as to leave nearest the shore what is heavy, and carry away to a distance and spread out what is more comminuted. Hence, banks of sand and beds of mud indicate always great depth of water, as well as comparative absence of turbulent action.

Keeping this principle in view, I now proceed to notice several localities where extensive beds of stratified sand and laminated clay occur at very considerable levels.

(1.) *Near Edinburgh*.—There is an enormous sand-bank which prevails over the whole district lying between Jock's Lodge and Stockbridge (in an east and

west direction), and between Drummond Place and Trinity (in a south and north direction), its length in an east and west, or rather in a NW. and SE. direction, being about three times its breadth. The depth of this bed, at some places where it has been wrought, is from 30 to 40 feet, and there the lowest parts were not reached. It rests on the boulder-clay. At Jock's Lodge, Eagle & Henderson's garden, and St Mary's Church, the upper limits of this sandy deposit occur,—all of these places being pretty much on a level, viz., from 100 to 120 feet above the sea. This bed of sand contains few or no stones, though occasionally particles of coal and shale are to be met with. It exhibits appearances of stratification, all more or less horizontal.

(2.) At Biletone, near Lasswade, there is another sand-bank, which runs in an east and west direction for many hundred yards. Dr Brunton, whose villa is situated on the south slope of this great bank, informs me, that the well for supplying his house is sunk through this sand to the depth of 64 feet, when it reaches the clay, and that the mouth of the well is below the summit of the sandy ridge by 40 or 50 feet. The thickness of this sand-bank exceeds, therefore, 100 feet. The height of this bank above the sea, I have not yet ascertained;—it cannot be less than 300 feet.

There are, near Loanhead and Lasswade, many other ridges or oblong banks of sand, running in an east and west direction.

(3.) On the south side of Stirling, there is a bed of sand at least 72 feet thick, through which wells have been sunk. The surface is about 90 feet above the sea.

(4.) In Berwickshire, about 2 miles south of Cockburnspath, the North British Railway cuts, for about a mile, through a series of sandhills, which probably formed a continuous bed before being cut through by burns. The cuttings show cliffs of sand from 60 to 80 feet in depth, and how much more sand there is below the line of railway is unknown. The railway is here about 120 feet above the sea.

(5.) In the counties of Nairn and Moray, on the one side of the Cromarty Frith, and in the counties of Ross and Cromarty on the opposite side, there is an enormous extent of arenaceous matter. In fact, the whole of the lower parts of these counties are overspread with unbroken beds of sand. Any one who has travelled from Inverness to Fochabers, must have been struck with the general flatness of the country, the entire absence of rocks, and the excessive abundance of sand, arranged generally in horizontal beds, and sometimes in the form of hills. The sand-hills exist, however, only in the lowest districts where the sandy deposit has been cut through more deeply than elsewhere by the rivers. The whole country here seems to have consisted almost entirely of sand, up to a level of at least 120 feet above the sea, which is about the height of the sandy flats near Fochabers, Forres, Elgin, and to the south of Nairn; at places nearer the sea-coast, where the sand-hills above referred to exist, the tops of these hills reach nearly to the same height.

In like manner, in the Black Isle and in the county of Ross, the accumulations of sand will be found no less great, and exhibiting many proofs that they have formed, with those on the county of Nairn and Moray, parts of one great continuous deposit. At the Muir of Ord, the extensive flat on which the market is held, consists of beds of sand about 108 feet above the sea, and which in composition very much resembles that on the south side of the Frith. It is beautifully white and remarkably fine and minute, so that, in the lower parts of the district where the deposit has been much cut up by rivers and rains, the sand is blown by the wind and does much mischief.

It is probable that the sandhills of Culbin, which were pointed out to me by Mr GRANT of Kincaith, on whose property they are, may be accounted for on the principles now explained. They are near the sea-shore, but their origin is not attributed by those best acquainted with them to the sea, though from what source the materials are derived, the inhabitants are by no means agreed. I am inclined to think that they are the remnants of that deep deposit of sand which formerly overspread the whole district, and which still forms the lofty white cliffs on the opposite side of the Frith east of Fortrose. The River Findhorn, which now enters the sea about a mile to the east of the Culbin sandhills, has evidently flowed, at a former period, into the sea at a place a good way to the west. It has thus cut up and removed much of the deep sand which formerly existed along this district, though some remnants have been left.

There is historical evidence of the great mischief done by the drift from these sand-hills, in consequence of its overspreading many acres of rich and cultivated land near them.

But whilst the great flat of sand on both sides of the Cromarty Frith does not much exceed 110 feet above the sea, there are places where sandbanks do occur, and in considerable quantity, at a far greater height. In passing along the turnpike road from Fochabers, southwards, the traveller sees extensive beds of fine white sand and clay, up to a height of from 800 to 1000 feet above the sea-level. These beds rest on boulder-clay, which, in some places, shews that it has been rearranged by water. The cliffs of sand are well exposed on the sides of the rivulets, occasionally presenting banks 100 feet high. To shew the depth and fine texture of this sandy deposit, I may mention that a ravine was pointed out to me, which, though dry at the time, I supposed to be the bed of an ordinary winter torrent. Its banks are from 20 to 25 feet high. What was my surprise when I learned, that it originated in an open ditch 4 feet deep, formed to carry off the surface water, and made only 11 years before.

In travelling across the Black Mount, situated between Invercromarty and Glencoe, I have been repeatedly struck with the extensive beds of sand and stratified gravel, which occur on both sides of the mountain up to a certain height. Their position, judging from some rude measurements with the sympiesometer, appears to be at 1100 or 1200 feet above the sea. Above that level, though there is abun-

dance of boulders and of gravel, the former are not rounded, nor is the latter disposed in stratified beds.

On the Highland road, and at the summit-level between the Spey and the Garry, there are great accumulations of gravel and sand at a height of about 1500 feet above the level of the sea. These are evidently not of local origin, but form part of a great deposit, which occurs in all parts of the country.

I observe that Mr CRAIG, in a letter to Dr BUCKLAND, quoted in the Proceedings of the Geological Society (1841, p. 415), speaks of beds of sand occurring near Glasgow, at a height of 350 feet above the sea, and near Galston, in Ayrshire, at a height of 500 feet above the sea; at both of which places they rest on the boulder-clay. I have not noticed any other published account of sand-beds.

I might, under this head, have referred to the deposits of laminated clay, and also to beds of fine gravel, at high levels, both of which clearly indicate the presence of great bodies of water, and in situations which prove that this water must have been oceanic. It is sufficient here to refer to the runcross brick and tile works near the sea-coast in all parts of Scotland, and which the demand for agricultural improvement is daily multiplying, at most of which there are extensive beds of clay finely laminated, and containing, generally, remains of marine testacea.

It remains for me to notice the third class of proofs before referred to, consisting of indentations on the land, and the formation of flats and terraces near the coast.

These indentations appear very clearly to be lines of ancient sea-cliff. They have to the eye all the appearance of sea-cliffs, presenting vertical faces fronting the sea, and hollowed out in the way that rocks are acted on by tides and waves. These cliffs form, at their base, lines which, when viewed on a large scale, are horizontal,—the only exceptions, being cases where deltas had been formed at their base, by streams which flowed into the sea at those points.

(1.) There are several sets of sea-cliffs to be seen in the Carse of Falkirk, the most remarkable of which runs by Airth and Dunmore, the base from 30 to 40 feet above the sea. This sea-cliff presents, for some miles almost continuously, a vertical front to the east or present coast, from which it is now distant about half a mile. The cliff is from 60 to 70 feet high, and presents the hollowing out, the overhanging ledges, and the other ordinary appearances of sandstone rocks washed and worn by the waves of the sea. Near the base of this cliff, at Airth Castle, in the burn flowing past it on the south, I found extensive beds of the common sea cockle. On the flats or terraces which occur above these cliffs, layers of sand are disposed in horizontal beds, indicating the presence and prevalence of deep water at a still higher level.

Upon these beds of sand there are some remarkable boulders of enormous size, the transportation of which will be considered in another part of this paper.

One of them (which goes by the name of the "Old Carlin Stone") is a block of the transition conglomerate, which forms great hills to the north and west of Doune, so that it must have been brought at least 20 miles. It is about 10 feet long, 5½ feet wide, and 6½ feet high, and weighing, therefore, nearly 30 tons. Its longer diameter points N.W. by W. by compass, which, if indicative of its line of movement, strengthens the conclusion that it came from the locality above referred to. Near this remarkable boulder there is a smaller one of coarse quartz rock, which evidently has come from the same distant quarter.

To the west of Carbrook there is a range of sea-cliffs, with a flat running up to them, which faces the north. The appearances, however, are not so unequivocal as those at Airth and Dummore, especially as the rock consists of hard trap, which forms a vertical wall running east and west for about a mile. In all probability, the sandstone strata through which this trap dyke had run have been washed away by the sea, when it stood at the height of these cliffs, the base of which is about 170 feet above the sea.

On the opposite side of the valley there is a range of cliffs, running for a mile or more from Logie Kirk through Airthrey and Westerton, by the mineral well, which present smooth faces to the south. A flat or terrace-race close up to the base of this cliff, which I estimated to be from 170 to 180 feet above the sea.

At two places along the base of this line of cliffs, ancient deltas, formed by streams which flowed into the sea when it washed the cliffs, may be studied with advantage. One of them is situated near the west lodge of Airthrey Castle; the other is near Montagu Cottage, a few miles to the eastward. The lofty Ochills, which are close to the line of cliffs, would easily supply the materials which formed these deltas.

In the higher parts of the valley, on both sides, ranges of cliff may be seen, consisting in some places of trap rock; in other places, and more unequivocally, of sandstone rock, as at Kair and Ochertyre (where beds of sea-shells occur at their base), at Gargunneck, and at Craigniven.

(3.) Along both sides of the Beauty Frith, and particularly the south-west side, there is a remarkable range of rocky cliffs nearly parallel with the present sea-shore, and some hundred yards from it, the base of which is from 20 to 30 feet above high-water mark.

(4.) In the Frith of Tay, two ranges of cliffs exist, the base of one 25 feet, and that of the other 87 feet, above high-water mark. Both of these cliffs may be seen at Newport, opposite to Dundee. The higher one runs continuously for a considerable distance at Inchture.

(5.) In the Frith of Forth, there is, on the Fife shore, a line of rocky cliffs, the base of which is from 15 to 20 feet above high-water mark. It may be very distinctly seen at Culross, to the west of Culross, Elie, and at Torryburn. It is prolonged by Kirkcaldy, and the old tower of Grange, as also between Dysart and

Easter Weyms, and on to Buckhaven. In this part there are numerous caves, which have evidently been hollowed out by the sea, their sides also presenting the smoothing and scooping out due to the action of water. Close to Buckhaven, on the west side, the rocky cliff ceases, but its place is taken by a cliff of boulder-clay at the same level. To the east of Buckhaven, a rocky wall-face fronting the sea again takes on, but at a level about 35 feet above high-water mark. This cliff can be traced continuously along the coast to the river Leven, and for some way up its course on each side. It holds on to the east of the town of Leven, and is seen stretching to Largo, and beyond it to the mouth of the Cockle Burn. At this last point two cliffs are observable, the one above and beyond the other; the lowest being about 15 feet above the sea, and three quarters of a mile from the shore; the other about 70 feet above the sea, and 1 mile distant.

Farther eastward, on the Fife coast, I have not examined. Between the long line of cliffs just described, and the present line of high-water mark, there is a bed of sand mixed more or less with broken shells.

(6.) On the west coast of Scotland similar appearances exist, though I have had less opportunity of observing them. Thus, in the Frith of Clyde at Cove, opposite to Dunoon, there is an old rocky cliff, the base of which is from 20 to 30 feet above high-water mark. From Dumbarton, eastwards, towards Dunglass Castle, and also to the west of the town, there is a striking range of cliffs, the base of which is about 30 feet above high water.

(7.) At Oban, and for several miles both south and north of that town, and also up Loch Etive, there is a very distinct line of sea-cliffs from 80 to 300 yards distant from the present shore, and the base of which is about 28 or 30 feet above high water. The town of Oban occupies the space between the old and present coast lines. This old sea-cliff presents a front to the sea of about 60 feet in height, generally not quite vertical, but hollowed out at its base, sometimes into deep caves. The rocks composing it are old red sandstone, conglomerate, and a friable trap. The interval between the base of these cliffs and the present sea-shore, is generally occupied with beds of sea-sand and gravel, evidently deposited by the burns and rivers which flowed into the sea when it washed the cliffs now described.

It is stated by Captain Varco,* that there is on the north side of Loch Tarbert, at a considerable height above the level of the sea, and some hundred yards inland, a range of rocky cliffs with caves in them, evidently formed by the long-continued action of the sea when at a higher level.

In almost all the cases now enumerated, there is a *terrace* more or less extensive, which comes up to the mural front, consisting of beds of sand or of fine gravel.

* Geological Society Transactions, vol. 1, p. 417.

(8.) The terraces now alluded to, also occur unconnected with lines of ancient sea-cliff; and so very commonly do they occur, that they are entitled to be classed under a separate head.

These terraces are more or less horizontal; and sometimes a succession of them may be seen, one above another, on the same part of the coast, to a height of several hundred feet. Many of them occur so frequently at the same level above the sea, even at distances far apart from each other, that there is strong reason for believing, that they had respectively formed continuous beach-lines all round the island.

If such is a true description of the terraces referred to, they not only afford good evidence that the sea has stood, relatively to the land, at a much higher level than at present; but they may afford some indication of the manner in which the old levels were altered,—not by one movement, but by a series of movements, interrupted by periods sufficient to allow of the indentation of the land, and the formation of flats of gravel, sand, or mud, on different parts of the coast near the ancient shore.

The evidence on this subject I, however, forbear from detailing at present; reserving it to a subsequent part of this memoir, when an attempt will be made to estimate more precisely the amount of change in the relative levels of sea and land, and the steps or interruptions which occurred in the course of the change.

From the foregoing views and statements, it most very clearly appears that, to a height of at least 1200 feet above the present level of the sea, Scotland had been beneath the waters of the ocean; and, therefore, that as the land gradually emerged, lakes would fill the valleys, and would continue to occupy them, until the detritus which blocked up the waters, was worn down and removed by the discharging currents.

3. It may be asked by those who are sceptical of these views, where all the detritus came from which was necessary for the blockage of the valleys, whether of Lochaber or of other districts? This question is of importance, in relation not only to the local inquiry, but also to the history and origin of the detritus covering the entire country. It is one, therefore, which peculiarly demands attention.

(1.) That boulder-clay, gravel, sand, and other detrital matter, had been deposited in the Lochaber valleys before they were emptied of the waters which formed the shelves, is evident from the fact before noticed, that in some places the shelves are formed out of that detrital matter. But it is necessary to go a little further back, and endeavour to ascertain whether, before the valleys emerged from the sea, the boulder-clay, sand, and gravel, had been deposited on the districts now covered by these materials? In other words, is there evidence that they had been transported and spread whilst our valleys and hill-sides, to a height of 1200

or 1500 feet above the present level of the sea, were still under the influence of the tides and currents of the ocean?

This question has been already answered, in so far as regards the beds of sand which, in some parts of Scotland, especially in the Highlands, cover extensive districts, to a height of at least 1000 feet above the level of the sea.

Now, if this be true of the beds of sand, it must be equally so of boulder-clay, which is allowed to be nearly the oldest of these superficial deposits. I do not agree with some geologists, who describe it as the very oldest; for at Cockburnspath, on a cutting for the North British Railway, I lately observed a bed of sand 6 feet thick, between the boulder-clay and the stratified rocks; and at the Portobello Brick Works, I am told by those well acquainted with the workings, that beneath the finely-laminated clay which is worked, there is coarse boulder-clay, and below it a bed of gravel.

But, generally speaking, it is undoubtedly true, that the boulder-clay must have been deposited antecedently to the extensive beds of sand before referred to, and therefore at a period when the districts now covered by the boulder-clay were under water.

Farther, it is found that many of the beds of clay throughout the country, which are worked for bricks and tiles, and are finely laminated, overlie, just as at Portobello, great deposits of boulder-clay; rendering it probable, that the materials of the laminated clay have been derived from the coarser clay beneath; and, accordingly, there is frequently found a layer or accumulation of boulders and large stones between the two beds of clay. This circumstance shews, that when the boulder-clay was spread over the districts now alluded to, water of considerable depth must have prevailed; and as in many cases marine remains have been found in working the laminated clay (as near Paisley and Dundee), it cannot be doubted that this body of water was oceanic.

The height at which laminated clay lying over coarse boulder-clay has been found, of course varies. In Berwickshire it is found covering a wide extent of country, from 200 to 400 feet above the sea.

The above inference, as to the prevalence of sea over the present continent of Scotland, when the boulder-clay was deposited, will be found to be greatly strengthened by a consideration of the old lines of cliff and terraces, before alluded to, as existing along the coasts at various heights, and ascribed to the action of the sea; for many of these cliffs have been formed out of the boulder-clay, and at the base of them enormous quantities of boulders occur, washed out by the action of the waves. From these considerations it appears clearly to follow, that the boulder-clay and associated detrital matter must have been spread over Scotland, at a time when the sea prevailed to a great height over this country. These considerations are independent of any theory as to the origin of the boulder-clay, or its mode of transport, and depend only on its position relatively to other deposits confessedly marine, and the mode in which it has been acted on.

(2.) If, however, we enter on that larger question, and give due weight to the circumstances which throw light on the mode of transport, we cannot easily come to any other conclusion, than that the boulder-clay was deposited when the present dry land, probably to the highest hill-tops, formed the bottom of the sea.

The circumstances now alluded to are well known to geologists, consisting, 1st, of smoothings and dressings of rocks on their west fronts; 2d, of the existence of tails or trainées on their east sides; 3d, the occurrence of scratches and furrows on rocks, apparently produced by the passage over them of heavy bodies. If these circumstances occur generally throughout the whole of Scotland, and more particularly in those districts where boulder-clay and débris abound, it seems impossible to account for them in any other manner than by supposing, that the transport of them is attributable to a violent movement of the ocean, before Scotland emerged from beneath its waters.

The parts of the country in which the circumstances just adverted to have been generally noticed, are in the Lowlands; but they are as strikingly observable also in the Highlands, and especially in the Lochaber valleys. It is important not only to the Lochaber question, but to the great geological question as to the origin of the boulder-clay, that instances of smoothings, dressings, and scratchings, should be multiplied; and therefore, I will notice some places where they have been, so far as I know, observed for the first time.

I have already mentioned, that in the Lochaber valleys boulder-clay and gravelly débris occur on the hill-sides, to a height of at least 1200 feet above the sea. In the ridge between Glen Roy and the valley of the Spey, which is about 1400 feet above the sea, there is an accumulation of boulders, but they are not imbedded in clay. The clay has probably, from the exposed nature of the situation, been washed away from them. I mention this point as the highest where I met with boulders; but I believe that there are spots in the neighbourhood, not visited by me, at a still higher level.

There is one circumstance which, in the Lochaber and neighbouring valleys, cannot fail to attract attention. I allude to the number of places where the rocks of gneiss, mica-slate, and granite have been rounded and smoothed, of which one example, taken from Loch Treig, has been given in the first part of this memoir. That this appearance arises not from natural structure, but from extrinsic causes, is the more manifest from two circumstances. The one is, that these smooth and rounded portions of rock invariably front one way,—viz. the west; and the other is, that the ordinary surface of the same rocks fronting other directions, presents a rough and rugged outline.

Another place where I was much struck with the appearances of wearing down and even polishing of the granite rocks—a coarse grey variety—is Leck Roy Hill, which separates upper from lower Glen Roy. This hill consists almost entirely of rock, and when Glen Roy was filled to its uppermost shelf, it must have formed a rocky culminating islet. The rounded portions of rock are to be

seen only on the west side of the hill; the other sides, and particularly those facing the east, are rough, rugged, and vertical.

I may here say in passing, that if a glacier had ever moved down the valley of Glen Roy, for which its length and small width admirably adapted it, this Lock Roy Hill must have presented unequivocal proofs of its operation, as it must have presented a complete obstruction to the progress of the icy current. — But then the rounding and smoothing of the rocks would have been on the east, north, and south sides, instead of being, as they exclusively are, on the west side.

I have alluded to Glen Fintoc as a branch of Glen Gluoy. At the mouth of Glen Fintoc, and on its eastern jaw, there is a large extent of rock (micæ-slate stratified), which presents a worn and smoothed surface at right angles to the planes of stratification. This worn and smoothed surface faces the west, and presents innumerable furrows or scratches, the direction of which, by compass, varies from west to WSW. by compass.

The position of this smoothed and striated rock, and the direction of the striae, are quite inconsistent with the movement of any glacier, either down Glen Gluoy or down the shorter valley of Glen Fintoc. The rock is nearly at the point of junction between the two glens, so that a glacier moving down either would scarcely have touched the rock, but would have expended all their force and weight on the opposite jaw of Glen Fintoc, which is lower down the valley.

The fact that the smoothed face of the rock is towards the west, and that the striae run in a direction from W. to WSW., very strongly indicate that the body which effected these appearances moved from a westerly direction, which is nearly across the direction of the valley of Glen Fintoc.

There is one circumstance which seems deserving of special notice, and for an explanation of which I refer to the annexed figure. A is that portion of Glen Fintoc, where it joins Glen Gluoy BB. *d* is the spot where the smoothed and striated surface of rock occurs, fronting the west, which is down Glen Gluoy. But the appearances of smoothing and scratching occur *only* where the smoothed and striated surface fronts the opening of the Glen Gluoy valley; for, on going about 100 yards up Glen Fintoc, so that a line due west would cut through the high hill marked *b*, the appearances become less, and at length cease altogether. These circumstances indicate, that the agent which had smoothed and striated the rocks at *d*, was of such a nature as to be aided in its operation by the open space of the valley, and to be interrupted or impeded by the interposition of the high hill at *b*.



There are no smoothings on the rocks at *b*. They are rough and rugged.

In every one of the Lochaber valleys which I visited, there are appearances of wearing down and smoothing on the rocks which have an open country on their west sides.

Along the great glen there are many places where these smoothed surfaces, on the hard granite rocks, forcibly arrest the attention of the geologist. Thus, at the east end of Loch Oich, and at the mouth of Glen Urquhart on the east side, there are great expanses of rock rounded and smoothed, facing the W. or WSW. by compass. At the place last mentioned, they are about 800 feet above the sea. At Drumnadrochet, the low rocky hills which abound there, besides being bare and rounded on the west, have tails of gravel on their east sides.

In the county of Ross, about 40 miles to the east of the place last mentioned, the river Alness, near its entrance into the Cromarty Frith, presents a cliff about 70 feet high, composed entirely of boulder-clay, filled with masses of primitive rock transported from the westward. On the surface of one of these boulders I observed a number of small striae, evidently formed by the passage over it of angular blocks or gravel, the direction of which I found by compass to be $W \frac{1}{2} S$.

It appears to me, that the legitimate inference from the foregoing facts is, that the boulder-clay and relative detritus was brought and spread over the country by a violent easterly movement of the waters which then covered Scotland,—bearing the hills on their west fronts,—leaving on their lee-sides, and in the valleys then existing, submarine accumulations of detrital matter,—smoothing the rocks, and occasionally striating them where most exposed to the force of the current. Ben Nevis and its associated range of hills would, of course, in that case, cause a greater accumulation on its lee-side than most other mountains in Scotland, and thus create ample means of blockage to the valleys east of Ben Nevis, and especially in the low country about Unachan and Low-Bridge, into which the mouths of these valleys open.

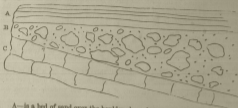
On the foregoing assumption, to which we are led by considerations altogether independent of the lake theory of the parallel roads, I can see no difficulty in explaining the blockage of the valleys to a height even greater than what that theory requires; and the remnants of boulder-clay and gravel which still exist in these valleys at the requisite height, not only confirms the soundness of that conclusion, but seem scarcely to admit of any other explanation.

I have mentioned, that the average direction of the current appears in the Highlands to have been $W. \frac{1}{2} S$. by compass. It is not in the least inconsistent with the foregoing views, that in the southern counties the direction appears to have been from the WNW.; for such variations, especially where the bottom of the sea was very irregular, are just what might have been expected.

In Stratherns (near Tomperran), the greywacke-slate rocks present smooth surfaces at right angles to the stratification, with striae running WNW. and ESE. Near this locality (about 3 miles NE.), there is a greenstone-dyke, running through the moor in a direction due east and west by compass. On the north side, it pre-

sents a vertical wall, swept clean, to the height of about 50 feet. On the south side, there is a mass of detrital matter, including large blocks of the dyke itself, indicating, that a powerful current had passed over it from some northerly point.

To the east of Burntland (in Fife) there is a sandstone quarry, about 200 feet above the sea, which has a covering of boulder-clay. The rock dips to the east, and at that part, the boulder-clay is 12 feet thick; but towards the outcrop of the rock, the boulder-clay thins off. The following section represents the arrangement:—



A—is a bed of sand over the boulder-clay, about 2 feet thick.

B—is the boulder-clay, a foot thick at the outcrop, and 12 feet thick towards the dip of the sandstone strata.

C—sandstone strata dipping to the west.

On the surface of this sandstone I found ruts and scratches, running in an east and west direction. It is plain, from these circumstances, that the boulder-clay had come from the west, that the ruts had been made by the boulders in their passage over the sandstone, that this had occurred when the sea prevailed over the spot, and that the land had afterwards risen by at least 200 feet.

In East Lothian, there are several places which present appearances of smoothing and scratching of the rocks. In addition to those mentioned by me in a paper published in a recent number of the *Edinburgh Philosophical Journal*, I would notice the trap-hill on which Fenton Tower stands. It has a number of smooth faces, which front the west. Many of these smooth faces, and particularly such as are horizontal, or nearly so, are scratched, the striae uniformly running WNW. by compass. This hill is about 250 feet above the sea.

In the channel of the Tower Burn, near Dungleass (East Lothian), there are cliffs of the boulder-clay, containing rounded blocks of marine limestone, mica-slate, gneiss, and coal. The strata which prevail at this spot, are old red sandstone. There are no beds of coal or of limestone, except to the north-west, a few miles off. The gneiss and mica-slate boulders must also have come from the same direction, and probably not less than 60 miles.

In Berwickshire, various places have recently been noticed by me, affording additional proofs, that the rush of waters which brought the boulder-clay was

from the westward. Thus, at Bogind, near Dunse, and about 500 feet above the sea, the stratified rocks consist of blue marls, whilst the surface of the country is covered with blocks of greenstone, brought from the rocks at Hume Castle and Greenknowe, situate 12 and 18 miles to the west; for there are no greenstone rocks in any other direction. The soil in which these boulders are embedded, is of a deep red colour, and has probably been derived from the old red sandstone rocks which abound near Hume Castle and Greenknowe. At Billie Mains and Auchincraw, situated in the north-east part of Berwickshire, there were formerly large blocks of granite lying on the fields, some of them now used as gate-posts,—derived, in all probability, from the rocks at Cockburn Law, situate about 12 miles to the WNW.

On the south bank of the Tweed, opposite to Paxton House, about 100 feet above the river, there is a greenstone boulder weighing about 3 tons, which most probably has come from Hume Castle, distant about 13 miles, in a WNW. direction.

Near Tillicoultry, in Clackmannanshire, there is, lying on a bed of boulder-clay, a greenstone boulder, about 10 feet in diameter, which must have come from the westward, a distance certainly of 3 miles, and probably a great deal more.

There is nothing so striking in geology, as the uniformity of direction in which the boulders and correlative débris appear to have travelled over a large part of the earth's surface. In Scotland, the evidence of this fact appears to be very decisive; and there is reason to believe, that even after the westerly rush of waters which transported the heavier materials subsided, there still continued a current from the same direction,—not, indeed, tumultuous, but sufficiently strong to move gravel and sand.

It is impossible to explain in any other manner the arrangement of the superficial deposits in the counties east of the great glen of Scotland. Near Inverness, there is beneath the surface soil, abundance of coarse gravel, and but little sand. Towards the eastward, as in the counties of Nairn and Ross, the sand becomes more prevalent, and the gravel less coarse. To the east of this, no gravel is to be met with; and after passing a district (about Fort-George, Fortrose, Nairn, and Ferres) occupied almost entirely by sand, then flats of mud and fine clay (as near Findhorn and Lossiemouth) succeed. These general features seem clearly to indicate, that after the boulder-clay had been deposited, a considerable current continued from the westward, spreading over the bottom in the shallower parts, near the hills, gravel and sand, and transporting to a distance the lighter sediment of sand and mud.

Before concluding the remarks which I have to offer on boulders and their mode of transport, I ought to notice an objection which is very commonly taken to the explanation now offered as to the origin of striae on them, and on smoothed rocks. It has been said, that no blocks of stone hurled along in the way I have supposed, even though forming part of a great mass of drift, could produce furrows

or even scratches on rocks; because, the moment that the angle of a block abutted against the surface of a rock, the moving block, instead of persisting in the act of rutting, would turn over, unless it were encased or set in some heavy body, such as a glacier. In all questions of this kind, the fact is worth many arguments; and I am able to supply a fact which appears important. In the Tower Burn, near Dunglass, there was lately a railway debacle, owing to the breaking down of a high embankment, by water accumulating behind it. The torrent carried down with it large quantities of earth and stones; in the course of the passage of which, innumerable scratches and ruts were produced on the solid rocks, and on large blocks of stone lying in the channel of the burn. I have procured one of the hardest of these blocks, composed of greywacke, which was scratched and rutted on this occasion. It will be found to have upon its upper surface, at least fifty striae all more or less parallel, and some of them of considerable depth. It is deposited in the Museum of the Society. The direction of the striae on this and other blocks, I found to be coincident with what had been the course of the torrent which passed over them. The striae thus produced are the more remarkable, that they were not on a surface of solid rock, but on a block or boulder capable of yielding to an impulse.

Whilst on this subject I may allude to the fact, that when, some years ago, Both's dam at Greenock gave way, a head of water about 28 feet high rushed through the town, carrying away many houses. My friend, Mr SMITH of Jordanhill, who examined the locality shortly afterwards, states, "that the streets and walls were marked with furrows. Masses of stone, and even of cast-iron, were mixed up with clay and gravel, without regard to gravity; whilst within the houses, every thing was covered with a thick layer of fine silt."* Mr STRAVANSON, Civil-Engineer, Edinburgh, mentions, in reference to this inundation, that a "mass of rock 18 tons weight, was borne along by the torrent to a distance of 30 or 40 yards."†

When such effects as these can be produced by the movement of small bodies of water, it seems scarcely possible to doubt that the transportation of the boulders, the smoothing of hill-sides, and the scratching of rocks, may be accounted for by a great oceanic movement.

(2.) In connection with the subject now treated of, there is a point which appears to me attended with some perplexity. I allude to the occurrence of large boulders, on the surface of *beds of sand and fine gravel*. Their transport to these situations cannot be attributed to a violent rush of waters, because, in that case, the beds of sand and gravel on which they rest, would have been disturbed or swept away.

The boulders in Dunmore Park before referred to, are in the situation now described. The counties of Nairn and Moray, which are remarkable for the ex-

* Memoirs of the Wernerian Society, vol. viii., p. 83.

† Transactions of Royal Society of Edinburgh for 1840.

tensive beds of sand covering the surface of the country, also present innumerable and very striking examples.

Not having had an opportunity of studying these surface-boulders so fully as I wished, I am not prepared to offer a confident opinion as to their origin and mode of transport. My present impression is, that these boulders have been derived from the wearing down of the boulder-clay; and that they have been floated off the ancient shores of a glacial sea, as the land rose out of the water, by the agency of ice. The flotation of such blocks by ice have been taken notice of in the Solway and Moray Friths, even in our existing climate, by Sir James Hall and Sir Thomas Dick Lauder.

(4.) Here, also, notice may be taken of another point connected with these superficial deposits, which is attended with still greater perplexity. I allude to the probable origin of the very remarkable ridges of gravel called *Koisa*, which are to be seen in those districts where much sand and gravel prevail.

Several of these I have described in a paper on the Geology of Roxburghshire, published in the Transactions of this Society. Those I have now to describe, and of which no notice has yet been published or even taken by geologists, are of the same general character.

a. There are several of these gravelly ridges in the neighbourhood of Falkirk. They all run nearly about east and west. They are a few hundred yards apart, and are from 40 to 70 feet high, with sides of pretty considerable steepness.

The most northern begins on the east side of Falkirk, though there is some reason for believing that it once continued as far west as Tap Hill, near the canal, at which place razor shells and seal bones were found. This ridge runs eastward through Callendar Park, by the south of Lauriston, crossing the turnpike-road there, passing Falmost on the north, crossing the Aron Water on towards Linlithgow. This ridge has been opened at several places for gravel and sand, so that its internal structure can be studied. It is quarried in Callendar Park, at the west side. Several beds of sand occur there, one of which beds in the section exposed is 18 feet long and 4 feet thick. The beds are nearly horizontal. In the gravelly part, some of the boulders are three or four times the size of a man's head; there are many blocks of porphyry and greenstone among them, rocks which occur *in situ* many miles distant to the westward. The next place where this ridge is quarried, is at Lauriston. It is quarried there for road-metal. The gravel is not so coarse as in the quarry previously mentioned. The interior consists almost entirely of horizontal beds of sand and fine gravel.

There is an arrangement characterising the beds composing these gravelly ridges, which is not a little singular. Though the interior is composed of horizontal beds of gravel and sand, there is an exterior coating of sand which mantles over the ridge, covering the edges of these horizontal beds.

The next great ridge to the south, begins in the middle of Callendar Park, and runs nearly to Linlithgow, a distance of 8 miles. The Edinburgh and Glasgow Railway is formed for some distance on the top of it. There is an extensive

quarry in this ridge in Callendar Park. Some of the greenstone boulders in it are several tons in weight, and very much rounded. It contains also boulders of mica-slate. In this quarry there occurs a bed of sand from 4 to 5 feet thick; and, lower down, a bed of clay, which throws out a spring of water.

A third ridge, farther south than the former, traverses the south side of Callendar Park. It may be observed running eastward for some distance along the north side of the railway.

A fourth ridge (called the Redding Ridge), lies on the south side of the canal, running nearly parallel with the rest. It is said to consist of clay.

These four ridges rise successively above each other in level, the top of the most northern being about 110 feet above the sea, and the most northern nearly 300 feet above the sea.

The upper surface of the north ridge seems to coincide with an extensive flat or terrace prevailing at Polmont.

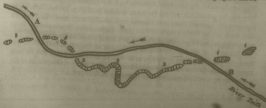
6. The next place where similar ridges of gravel and sand occur to any remarkable extent, is on the west side of Loch Lomond, near the Boat of Balloch.

There are at least two ridges there. One of them can be traced for at least a quarter of a mile; another for about three miles. They run north and south, or nearly parallel with the general direction of the existing valley of the lake. At the west side of the turpicks-road, at the north gate of Cameron House, one of these ridges occurs. Its height is about 40 feet in some places. Its sides are almost vertical. At its north end it is only from 10 to 12 feet high.

Farther south, another and the largest ridge occurs. It runs through the whole park or policy of Cameron House.

At Tillichewan House, another similar ridge occurs; it is, however, not quite so steep or so high; and, instead of running continuously in a straight line, it takes, near its south end, a sudden turn to the west, in this respect conforming with the range of high ground which enclose the valley on the side where it occurs.

(2.) The ridge of gravel and sand at Callendar, which by some has been described as the vallum of a Roman camp, and, by others, as the terminal moraine of a glacier, belongs undoubtedly to the same class. The following figure shows



the form of it. A B is the River Teith, flowing to the eastward. The parts marked 1, 2, 3, are ridges of gravel, now separate, but probably at one time connected. The interior consists of sand and fine gravel. The height of this gravelly ridge is from 30 to 50 feet.

c. Another locality where these ridges occur is Baldovan, near Dundee. There are three of them there, all running parallel to the course of the River Dighty, which they adjoin, and rising to a height of from 40 to 60 feet above the level ground. These three ridges, though now separate, have originally formed one continuous ridge, having been apparently cut through by the river. They seem to consist chiefly of sand, but they contain also some gravel, in which there are pebbles of grey-wacke and porphyry, apparently derived from hills to the north or SW. The general direction of these ridges is east and west.

A ridge, or oblong mound of gravel and sand, about a hundred yards in length, occurs on the south side of the turnpike-road between Haddington and Linton.

At Arthurst, near Longtown, there is a remarkable ridge composed of sand and gravel, which runs for several hundred yards, and at a height of from 60 to 70 feet above the adjoining flat country. Among the pebbles in it, I found numbers of red granite, derived probably from Kirkcaldbrightshire and south part of Ayrshire, and transported, therefore, from the NW., a distance of at least 60 miles. The top of this ridge is from 130 to 150 feet above the sea.

The ridges now described have steep sides. They resemble, in their general features, the accounts given of the *Oars* in Sweden, and the *Horse-backs* of the United States.

It will be observed in regard to those in Scotland, (1), that when there are several in one locality they are more or less parallel to each other, and agree in height, form, and composition; (2), that they are parallel to the general line of the river, or lake, or valley, in which they occur.

That they must have been formed in some way by water, is evident from the stratified beds of sand and clay which they contain.

In connection with these ridges, I may take notice of some remarkable accumulations of gravel and sand at Lossiemouth, in the county of Moray, and which are popularly called "The Standards." There are, I think, 6 or 7 of these ridges. They are close to the sea-shore, forming high ramparts with hollows between. They run for several miles along the coast, and are from 16 to 18 feet high. Near Lossiemouth they are composed of sand and small gravel; near the Spey, for they reach almost to the mouth of that river, distant from Lossiemouth 8 or 10 miles, they are said to consist of rounded pebbles of considerable size.

The belief of the most intelligent inhabitants of the neighbourhood is, that these gravelly ridges were formed in some way by the river Spey. But the only reason for this opinion which I could obtain was, that many of the pebbles in the ridges can be identified with rocks in the valley of the Spey.

It seems probable that the gravelly ridges in question have been formed between the current of a river on the one side, and the waves of a stormy sea on the other. I observed at Stonehaven, at the mouth of the Esk near Montrose, and at the Duglass Burn, illustrations of the formation of such beaches. At the mouth of the North Esk, the river, when it impinges on the shore, suddenly turns to the north, and runs for about a quarter of a mile on the inland side of the beach, which is thus formed into a sort of rampart; and if there were to be a sudden elevation of the land or sinking of the sea, this rampart or ridge of gravel and sand would be precisely similar to one of those before described. As the process of continental elevation or oceanic subsidence went on, other sea-ramparts at a lower level would be formed, and thus a succession of them, similar to those at Leaskmouth, would be the result.

At the mouth of Duglass Burn I observed two such beaches,—the highest one formed evidently between the river and the sea at spring-tides, and the lowest formed at neap-tides, with, of course, a difference of a few feet between the heights of the two.

It is exceedingly probable that the ridges at Falkirk, and on Loch Lomond, may have been formed in this way when the sea stood at their level. They are all, more or less, parallel with what must then have been the line of the ancient coast; and at or near the places where they occur, rivers flowed into the sea.

Whilst offering this explanation as a probable one, I wish, at the same time, to suggest another, which has also much to recommend it, viz., that these parallel mounds of sand and gravel may have been formed, not on the margin, but at the bottom of the sea, not far from the then existing shore. This last view I advocated in a paper published in the Transactions of this Society a few years ago, with reference to a remarkable ridge of gravel remains, for 4 or 5 miles parallel with the existing sea-coast in Northumberland, and distant from it about 3 miles.

It is well known that ridges of gravel and sand can be formed at the bottom of the sea by the unequal action of currents, of which many examples exist in most estuaries, and are laid down in the sailing charts of the Thames, the Rhine, and other great rivers. These charts show, that the ridges of gravel and sand now forming in such situations are often from 50 to 80 feet high, exceedingly steep, and, though generally running in lines parallel with the adjoining coast, sometimes also run in curved lines, doubtless produced by eddying currents. A similar bank parallel with the existing shore exists in the Solway, being known to mariners under the name of the *Sillo*.

The gravel ridges last alluded to were probably formed, in many cases, during the rising of the land, and the consequent shallowness of estuaries. During this process, and especially if at any period it went on rapidly, there would be strong tides and currents, sometimes acting in such a manner as to produce anomalous, or even fantastic assortments of gravel and sand. In this way it is not difficult

to account for the formation of the ridges at Callendar, Baldoon, Loch Lomond, Kaim-rod (near Dalkeith), Kaim-flat (near Kelso), Kaims (near Greenlaw), and other places, where these curious formations occur.

There are some other combinations among the gravels and sands, which, though a little anomalous at first sight, have been probably occasioned by the shallowing of estuaries.

In the district between Findhorn and Lossiemouth, extensive beds of laminated clay are overlaid by beds of sand and fine gravel. At first it is difficult to understand why the sediment of lightest specific gravity should have been deposited first. This difficulty, however, vanishes, when it is remembered that the whole district eventually rose out of the sea; so that a place over which a great depth of water at one time prevailed, and in which a clay sediment had been deposited, would afterwards be covered by much shallower waters, and agitated by currents capable of moving sand and gravel.

As an example of the same thing, I give the following section taken from a railway cutting near Inveresk.

Surface Soil, 5 Inches

Fine Gravel, 15 Feet Thick

Sand & Clay in Horizontal Layers

The bed of sand and clay represented in this wood-cut is over a stratum of laminated clay at least 12 feet thick, lying over boulder-clay.

On the Fishcove Railway, the following arrangement was observed by me.



4. It only remains to notice the raised beaches, as they have been generally termed, which fringe the Scotch coasts.

(5) The gravel in this section contains water-worn pebbles of porphyry, diorite, felspar, greywacke, coal-measures, and coal. This detritus has probably been lodged here by the River Esk, when it flowed 40 to 50 feet higher than at present.

In various publications, accounts are to be found of the occurrence in Scotland of sea-shells in beds a few feet above high-water mark; and in a paper written by me on the Mid-Lothian Coal-field, there is a short notice of an old line of sea-cliff and terrace running along the south side of the Frith of Forth to the south of Dunbar. Soon after the publication of that memoir, I began to discover traces of what appeared to me old sea-cliffs and sea-terraces, at higher levels, and not in the Frith of Forth alone, but on many other parts of the coast.

My observations were at first not made with the precision necessary for such an inquiry, and, therefore, I am unwilling that very much reliance should be placed on them. I may state, however, that my observations, when properly classified, indicate a series of old cliffs or terraces, eleven in number, rising to a height of 750 feet above the present level of the sea.

It is scarcely necessary to observe, that these terraces and cliffs, as they now exist, vary much in continuity and distinctness. In the *first* place, those which are lowest and most recent, are, of course, the best preserved. In the *second* place, it would depend on the set of tides, on the exposed or sheltered position of the coast, and on the nature of the strata, whether the land would be indented so as to form a cliff, or acted on so that a shallow flat would be produced. In the *third* place, it might happen, that, after a cliff or a terrace had been formed, either of them might be undermined and obliterated by the subsequent action of the sea.

For these reasons, though in most parts of the coast, the three lowest cliffs can be pretty distinctly traced for great distances, at the respective heights of about 12—26—30 to 40, and from 50 to 70 feet above the sea. The higher and older cliffs occur only in isolated patches, and almost the only means of identifying them, are by the height above high-water mark, and the existence near them of other well-known beach-lines, forming links of the series.

That the cliffs and terraces now alluded to, are due to the action of the sea, when it stood at the levels indicated by them, no person who has examined them can doubt, especially as it is known from other sources, that the sea has reached far higher levels. But it has been thought, that these cliffs and terraces prove more than this,—*viz.*, that, in the elevation of the land, *rock* took place, which afforded time to eat into the land, and also to spread out the materials so derived into flats, at particular levels. At first sight, this inference appears most legitimate; and yet some doubt as to the soundness of it, in all cases, may be surmised. For, supposing that the movement of the land was very slow, it is possible to conceive, that, at various points along a coast, the set of the tides and currents might form a line of sea-cliff, and that, as the process of elevation went on, the set of the tides and currents might be suddenly changed, and thus the coast, when raised still higher, would, along a certain level, present at certain points the appearance of a well-marked sea-cliff. On the other hand, if it should appear that

in the series of successive sea-cliffs and terraces, there are some two or three which besides being everywhere at exactly the same level, are much more distinct and marked than the others, it would be difficult to deny that the land, when these lines were formed, must have risen more slowly, if not been altogether stationary. My own observations lead me to believe, that, on the coasts of Scotland, there are certain lines of cliff and terrace along the same level, or nearly so, which are much more frequently met with, because originally more strongly marked than others; I allude, in particular, to those at heights respectively of 12 feet, from 30 to 40 feet—from 60 to 70 feet—from 120 to 130 feet—and from 170 to 186 feet; and it greatly strengthens the correctness as well as importance of these observations, to find that raised beaches have been described as existing on the coasts of England and Ireland, at the heights of all the lines just mentioned, and particularly the three first.

But here it is proper to observe, that whilst there is abundant evidence of an elevatory movement, there is also some reason for thinking, that there was not only a suspension of that process, but a subsidence of the land, followed by a renewed elevation. The grounds for this opinion may now be briefly stated.

When the Edinburgh and Newhaven Railway was being constructed, there was found on the north of the turnpike-road lying between Leith and Golden Acre, an extensive bed of sand, about 10 feet thick, below it a bed of peat 1 foot thick, below it a bed of laminated blue clay about 10 feet thick, and below it the well-known boulder-clay. The bed of peat contained roots of trees, which evidently had grown in the clay, as their roots were found passing through the peat into the clay. These roots belonged apparently to the hazel; but the only parts undecayed were the bark. In this peat-bed there were stems of reeds and other marsh plants, and numbers of small seeds of some shrub, not unlike those of a species of whin. These seeds, Mr M'Nab, of the Experimental Gardens, attempted to germinate, but without success. There were also some elytra of beetles. This bed of peat is from 70 to 80 feet above the sea. I traced it for at least 100 yards along the cut of the railway, in a north and south direction. How much it extends in an east and west direction, I had no means of ascertaining. But it certainly extends to the westward for at least a mile.* Over this bed of peat, there is, as already mentioned, a stratum of sand, which at the railway cut is 10 feet thick, and appears to form a continuous deposit over all this district. That this thick bed of sand must have been deposited in deep water, is undeniable; and, therefore, I am inclined to hold, that when trees and shrubs were growing on the

* The late Captain BOWMAN of Warble showed to me a statement of the strata gone through in sinking two coal-pits on his property, which adjoins the locality alluded to in the text. At Pit No. 1, which was 71 feet above the sea, a bed of sand 9 feet thick was first gone through, below which there was 114 feet of clay, first soft, and then hard and stony. At Pit No. 2 (200 yards to the west of Pit No. 1), the first bed gone through was 2 feet of "sand and soft clay," below which was 21 feet of "stony and black clay."

surface of the fine blue clay above mentioned, either the land here had sunk down, or the sea had risen, so as to submerge this ancient forest, and allow of the deposit of this extensive bed of sand over it.

I have, in a former paper, pointed out at least one other locality in this neighbourhood, which indicates a submergence of the land; and a good many notices of similar facts are mentioned by others. Below the clay-bed, in which the bones of the whale were found near Blair-Drummond, there is a bed of spongy peat, containing remains of alder and birch.—(*Wes. Mag.*, vol. v., p. 440.) On the east side of Stirling (near St Ninian's Well), at Polmaisee, and at many other places in the Carse, a bed of peat has been discovered, with trees in it, which is covered by a bed of laminated clay from 12 to 15 feet thick. In the estuary of the Tay, there is a well-known peat-bed, several feet in thickness, through which trees stand up erect, with their roots fastened in the subjacent clay. The peat-bed and trees are overlaid by horizontal deposits of clay and sand, filled with sea-shells, to the depth of from 15 to 20 feet. Similar beds of trees and shrubs, below the present level of the sea, have been found in Largo Bay, the Cromarty Frith, in Orkney, the Isle of Man, and various parts of the south of England. These facts, though by most geologists considered as indicating a general depression of the land, are by others attempted to be explained by local subsidence, or by local inundations of the sea. But when, as in the cutting of the Newhaven Railway, the ancient forest—from 70 to 80 feet above the present sea-level, is covered by what is obviously an extensive marine deposit, no other explanation is possible, than a sinking of the land beneath the waters of the ocean, and a subsequent emergence; or, alternatively, a rise in the level of the ocean, and a subsequent retrocession of its waters.

In the foregoing observations I have, for the sake of convenience, spoken of the elevation and subsidence of the land, as if the change in the sea-levels was brought about entirely by that cause, and not by any rise or recession of the ocean. It seems to me, however, that geologists ought not to reject, as altogether unworthy of consideration, the idea that some of the changes in the relative levels of sea and land may have been caused by a rise or fall of the ocean. If there are occasional elevations of the dry land, why may there not also be elevations and subsidences of the sea-bottom, and to such an extent as to affect the level of the entire ocean? We know that, during the tertiary period, there was but a small portion of the European continent not covered by the sea; and, judging from the enormous accumulations of animal and vegetable remains in the strata of that period, it is plain that the seas were generally shallow. That partial elevations of the land subsequently took place, need not be disputed; but that there are extensive tracts of Europe, especially in Russia, which appear to have undergone no elevatory movement, appears highly probable from the account of their perfect horizontality and integrity, given by Sir ROBERT I. MUSCHUSSE. Where is the absurdity

in supposing that depressions took place on the earth's surface, into which the waters of the ocean retired? But the supposition is more than possible; for Professor EDWARD FOONIS has, from botanical considerations, inferred that a great continent existed to the west of Europe, which occupied at least two-thirds of the Atlantic Ocean, and which has sunk into the bowels of the earth. If the Atlantic Ocean has been formed by a depression in that part of the earth's surface, the reasoning would apply, with even greater force, to the bed of the German Ocean, seeing that the investigations of Professors OWEN and FOONIS require, for the migration of races, a continent to connect the British islands with the continent of Europe.

I have adverted to this question in connection with the lines of old sea-cliff, because it appears to me, that they might, to some extent, be made instrumental in elucidating that question. If it appears, on an exact and extended survey of these lines, that they are not horizontal, but slope as some beach-lines in Finland are said to do, then there would be clear proof that the land had risen; and, according to the gradients of each set of cliffs, some inference might be drawn as to the nature of the elevatory movement. But if, on the other hand, it should be proved, that the several lines of cliff are exactly horizontal, and that they can be respectively traced along the coasts of Scotland, England, Ireland, and France, at exactly the same relative heights above the sea, then it would be difficult to hold that the land had been the moving body, especially if there had been not only elevation, but an intermediate subsidence.

This interesting inquiry has lately been undertaken by Mr R. CHAMBERS of Edinburgh, who thinks that he has been enabled to identify in England and France several of the Scotch sea-terraces; and, knowing that he is about to publish the result of his investigations, I have refrained as much as possible from going into any details on this subject. I may, however, observe, that I have been much struck with the accounts given in recent geological publications, of the successions of raised beaches, one above the other, and all apparently horizontal, which occur in the coasts of many countries, as Norway, Greece, Canada, the United States, and South America; and I find that the heights above the sea of several of these beaches coincide exactly or very nearly with sea-cliffs or terraces in Scotland. Thus MORS BRAYAN speaks of a horizontal terrace on the Norwegian coast, at the height of 60 feet. Mr LYELL, Captain BAYFIELD, and Mr LOGAN, speak of terraces, with marine shells, in Canada, at various heights from 60 to 400 feet. Mr LYELL describes two terraces on the Ohio, at the respective heights of 60 and 120 feet. Mr DARWIN describes terraces in South America at the respective heights of 25, 70, 120, and 170 feet;—all of which are identical in height with old cliffs or sea-terraces in Scotland. It would, indeed, be a highly important geological discovery, were it to be proved that in distant parts of the earth's surface, there are lines of sea-beach at precisely the same height above the medium level of the sea; and

the bare possibility of such a discovery, to state it no higher, should induce future observers to ascertain the height of raised beaches above the high and low water marks with as much exactitude as possible.

It may be asked, at what period these raised beaches, and the deposits connected with them, were formed. The evidence, so far as it goes, indicates, that at all events the most recent were formed within the human period.

I have several times met with the bones of the ox and the horse in connection with the most recent of the raised beaches before described. The former I found near Dunlaga, at a height of about 12 feet above high-water mark, completely enveloped by sea-shells. Bones of the horse I found at Dirleton, among sea-shells, at a height of 120 feet above the sea.

In Cunnecu's brick-work, at Stirling, there were found in the course-clay about 27 feet below its surface, and 8 feet above high-water mark, the head and horns of a species of deer. This clay contains marine shells.

In constructing a bridge over the River Avon, in the same Course, the horns of an elk and the cranium of a small-sized bullock are said to have been found.

Mr HousE DUNSMOND informs me, that when the whale bones were discovered on his property at Blair Drummond, there was found amongst them an instrument which evidently had been used by the inhabitants of the country at the time when these bones were deposited. This instrument was of the rudest and most primitive description. It consisted of a portion of a deer's horn, having a hole bored into it, for the reception of a stick, as it contained the remains of rotten wood. A similar instrument was found among the bones of the Airthrey whale. Mr HousE DUNSMOND's idea is, that these instruments had been used as harpoons, or in some other way in connection with the whales when they were stranded. These bones are, it will be remembered, from 20 to 30 feet above high-water mark, and some miles from the sea.

It may be convenient, in conclusion, to recapitulate the series of changes which I suppose to have occurred, embracing the period when the Lochaber shelves were formed.

1. In the *first* place, there appears to be evidence of the entire submersion of Scotland beneath the waters of the ocean before the formation of these shelves.

The deposits of boulder-clay, gravel, and sand, though respectively differing in character, must have taken place when the districts now occupied by them formed the bed of the ocean; and as these deposits occur in all the Lochaber valleys, and have evidently been acted on by the waters (whether marine or lacustrine), which produced the shelves, these shelves did not exist till after the land began to rise out of the sea.

2. The present valleys of Lochaber, as of all other parts of Scotland, were, when submerged beneath the ocean, to a great extent filled with the various de-

deposits of boulder-clay, gravel, and sand; and these deposits, as the land was elevated, were gradually removed by the operation of rivers and meteoric causes,—remnants of them being left on the hill-sides.

3. When the valleys were thus filled or choked by detritus, lakes would be formed in them, which would sink from one level to another, as the detritus was removed, and, in many cases, form shelves or parallel roads more or less distinct.

These lakes would be very numerous when the land first emerged from the ocean, but, in the course of time would be drained, except where the blockage was produced by more permanent materials than detritus.

4. The drainage of these lakes and their depression from one level to another, would go on more slowly than the elevation of the land; so that, when these lakes were forming shelves at any given height, the ocean would probably be producing indentations on the coast, at half, or less than half, of that height above the present sea-level.

Hence the shelves formed by extensive lakes, will generally be much more distinct and unbroken (being of more recent date) than the raised beaches on the coasts of Scotland.

5. The existence of these raised beaches round the Scottish coasts, and distinguishable to a height of about 750 feet above the present sea-level, so far as yet examined, appear to indicate that the elevation of the land was interrupted by *rusts* or by a retardation of the process at certain periods.

6. There are circumstances, however, which suggest the probability of a subsidence of the land which was preceded, as well as followed, by elevation.

7. If, on an exact and extended survey of these raised beaches, it should be found, that many of them at different levels can be traced continuously, along not only the Scotch coasts, but those of England, Ireland, France, and more distant countries, and that these beach-lines are everywhere horizontal, the inevitable conclusion would be, not that the land had risen and subsided at different times, but that the ocean had risen and fallen.