

to subsist on distilled water; they must therefore be supported by some organic remains. We have tried to feed them with the stalk and sporules of the protococcus without any conclusive result. Inclosed in a vessel surrounded with a cold mixture, they are unable to support a temperature of —18 centigrade degrees. This degree of cold kills them in a few seconds.

These facts ought to be impressed on the memory of those who have occasion to visit glaciers; they shew that there is a peculiar organisation to be studied in such places. A numerous series of microscopic beings belonging to the vegetable and animal kingdom live and prosper in the bosom of the ice, at a height of 2500 metres above the level of the sea.

On the other hand, it is not less clearly proved, according to the laws which regulate the movements of glaciers, that the entire mass renews itself at the end of a certain number of years, and contains the mineral, vegetable and animal remains which exist on their surface and in their interior; they all reach in succession the terminal talus, and are again found in the waters which flow from the inferior vaults. Hence the origin of their great impurity, and the grey, milky colour, without transparency, which characterises them.—*Comptes Rendus de l'Academie des Sciences*, t. xxiv. p. 1093.

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*On the Parallel Roads of Lochaber, with Remarks on the Change of Relative Levels of Sea and Land in Scotland.*  
By DAVID MILNE, Esq., F.R.S.E., Member of the Wernerian Natural History Society; of the Geological Society of London, &c.

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 1839, 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 Roderick I. Murchison, Mr Lyell, and Mr Horner, 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, 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 shew, 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 de-

scribed 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 Horner, 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. Murchison, Mr Horner's predecessor, in his anniversary address of 1843; in support of which, he refers to the concurrent opinion of M. de Beaumont 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. Stevenson, 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 farther 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 29 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 213 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 admit of the waters flowing over that level as over a lip. Thus the uppermost shelf of Glen Gluoy No. 1, in Sir Thomas Dick Lauder's Memoir, is (as he explains) exactly coincident with the water-shed ridge which divides Glen Gluoy 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 Gluoy 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 Mukkul 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 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 rever-

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 Pattaig 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 Col-

larig, 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 Mukkul. 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 3 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 29 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 Mukkul.

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 this 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 bared 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 accumu-

lation 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 Glaster, Glen Spean, and Glen Treig.

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 29 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 29 feet in the course of 6 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 Tombhran and elsewhere, in order to shew that the water did produce marks at some places, and not at others. But, from the faintness of those 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 in 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 shewn how circumstances caused that anomaly at Glen Roy and its adjoining valleys. But he has not shewn, and cannot shew, 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 Kilfinnin, 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 action 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 Frith of Tay, the tide rises at Perth 18 inches above the level at Newburgh. The tide at Alloa 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 eat 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 should 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 Glen 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 Tom-bhran 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 Achavaddy, 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

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\* 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 points last mentioned.

former writers, and especially Mr Darwin, 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 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 Bohuntine 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 Tun-drun 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 rivulet 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. 53,) 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 Makkul. 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 Tomnempairachin, 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 Tomnahurich at Inverness (about 180 feet high and half a mile long), and a hill to the west of it (240 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 900 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 Spean 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 Kilfinnin,\* about 10 miles to the eastward, and which he says is (by his barometric observations) about 40 feet above the highest

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\* 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 Kilfinnin, depends entirely on ocular inspection and barometric measurements.

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, 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 236 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 Gluoy, as seen at the water-shed between it and Glen Roy, and *on a level with shelf* 1. The deposit occurs also at



Clenichan, 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 200 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 Inverournan, near the summit level between the two valleys, which I estimated to be about 1030 feet above the sea, there is great abundance of sand and gravel. On the Black Mount, about 4 miles north of Inverournan, 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 into 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 Benofflap, 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 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,

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\* Jameson's Edinburgh New Phil. Journal, vol. xxxiii. p. 236.

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 that 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. Agassiz 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. Agassiz 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 if, 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

Gluoy, 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 786 feet above the lake, and 1680 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 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 facts were all to the east. It was clear, on an inspection of these knolls, that they had been worn down on their west sides; and the smoothed sides 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. Agassiz, in the paper before alluded to, says that he will never forget the impression he experienced "at the sight of the terraced

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\* 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, shewing still more clearly that the smothering agent had crossed the valley of Loch Treig, in a direction not parallel with its longer axis, but obliquely to it.

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 gray 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 show 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 shewn 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 Inverournan (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  $183\frac{1}{2}$  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  $93\frac{1}{2}$  feet,—when the third shelf was formed; after which it sunk  $183\frac{1}{2}$  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

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\* These measurements were made by a mountain barometer, checked by the sympiesometer.

and diluvial debris, which was gradually eat 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.

(2.) 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 Auchreach farm-houses, Enich farm-houses, and as far as Crianlarich 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 Dalmally, there is a flat or terrace about 40 feet above the present level of the lake; and which manifestly indicates a subsidence of its water 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  $\frac{1}{4}$  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 Teith 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 eat 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 Konin 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 traces on the hill sides, which clearly shew the action of water. Three very distinct markings of this nature are traceable near Dodd's Mill, at Hounslow, at Carfrae Mill, and at Annfield near Channelkirk. 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 shew 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 parts 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 Gainslaw, it is 44 feet; opposite to Finchie, it is 55 or 56 feet; opposite to Paxton, it is 58 feet; at Norham, it is 93 feet above the sea.

At New Rattray (in the parish of Blairgowrie) I observed an extensive flat, or ancient haugh, with its cliff or bank about 80 feet above the River Erigh.

On the Isla, above Airley Castle, there is haugh land on both sides, about 30 feet above the present level of the river.

On the River Garry, about  $3\frac{1}{2}$  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.

*Remarks on the Trade Winds and other Currents in the Atmosphere, at Barbadoes; with an Attempt to Develop the Causes of Hurricanes in the West Indies.* By ROBERT LAWSON, Assistant-Surgeon, 47th Regiment. Communicated by the Royal Scottish Society of Arts.

(Continued from page 154 of Volume xxxix. of this Journal.)

PART II.—*The Causes, &c., of Hurricanes.*

40. There are, at present, two views with regard to the phenomena of hurricanes, which have attracted a good deal of attention. One of these, advocated by Mr Espy, of Philadelphia, assumes that the aqueous vapour in a given column of the atmosphere becomes condensed, and that the latent heat of the vapour, which is consequently liberated, elevates the temperature of the surrounding particles of air, thereby rendering the whole column specifically lighter than the neighbouring portions of the atmosphere; and these, accordingly, in obedience to the laws of gravity, flow inwards from all points towards its base, while it rapidly ascends. On this supposition, the winds around the base of the ascending column should all flow in the direction of the radii of a circle, in the centre of which the base of the ascending column is placed. Professor Hare, of the University of Pennsylvania, has adopted the opinion of Espy as to the ascending central column, and the centripetal motion of the surrounding air, but conceives that the upward current may, with more reason, be ascribed to the attraction of an electrified stratum of air,