

ON THE LAKE BASINS OF LAKELAND.

By J. E. MARR, M.A., F R S., SEC.G.S.

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TWENTY years have gone by since the late Mr. Clifton Ward published his observations on the depths of the lakes of Cumberland and Westmorland, and his views on the origin of those lakes * ; the knowledge of the physical features of the lakes obtained by Ward and by earlier observers did not appear to be adverse to the acceptance of the glacial erosion theory of lake-basins ; and Ward himself, in the papers referred to, argued strongly in favour of that theory. In the absence of fresh information, many geologists have accepted this theory as far as the lakes of Cumbria are concerned. Recently, however, a most important contribution has been made by Dr. H. R. Mill to our knowledge of the physical features of these lakes,† under the title of “Bathymetrical Survey of the English Lakes,” and it is desirable to see how far the new information at our disposal tells for or against the ice-erosion theory. Dr. Mill remarks that “the object of our survey was to lay down on maps the isobaths or contour-lines of depth, and so to compare the scenery of the subaqueous with that of the sub-aërial region of the Lake District” ; and modestly adds : “I fear that this comparison, however completely it may be made, cannot throw much light on the origin of the lake-basins, for the original hollow, whether it were the result of cracking, or crumpling, or scooping, must be by this time effectually covered by the blankets of ever-thickening sediment, through which no distinct evidence of primitive form can be felt.” It is the object of the present writer to show that Dr. Mill’s work does afford considerable information concerning the origin of the lake-hollows, and the information is all the more valuable, inasmuch as it was collected without any desire to support or overthrow any particular theory.

It is generally admitted that the hollows in which lakes of the type we are considering lie can only have been formed in two ways ; either (1) by erosion of the hollow beneath the surface of the water by some agent other than water, presumably ice ; or (2) by the formation of a dam across the valley, which dam may be produced (a) by earth-movement ; or (b) by accumulation of loose material, such as landslip-detritus, scree, rubbish falling down snow-slopes, or glacial deposit, sub-aërial or marine. If formed by erosion, through the operation of some agent other than water, there should be marked differences between the

* *Quart. Journ. Geol. Soc.*, vol. xxx, p. 96 ; and vol. xxxi, p. 152.† *Geographical Journal*, vol. vi, pp. 46, 135.

scenery of the subaqueous and that of the sub-aërial region, whilst, if the lake-hollows have been formed by the formation of a dam across the valley, the subaqueous scenery may be expected to resemble that above the water-level. Dr. Mill's detailed work is eminently adapted to give us information upon this point, and I propose at the outset to consider it. There is, unfortunately, great difference of opinion as to the exact nature of the erosion which land-ice is capable of performing, and if anyone goes so far as to assert that the effects of ice are practically similar to those of running water, it would be difficult to bring forward convincing evidence as to the manner in which the lake-hollows were produced. There is, however, one structure which everyone will admit to be characteristic of ice, viz., the *roche moutonnée*, and I hope to prove that the nature of the *roches moutonnées* of Lakeland supplies us with a valuable argument. In discussing the various details of subaqueous scenery, we may conveniently consider the subject under the following heads: Submerged river-valleys, subaqueous alluvial flats, subaqueous cliffs, and *roches moutonnées* near water-level.

(1.) *Submerged River-Valleys*.—There are two ways in which the evidence of a submerged river-valley may be detected—firstly, by observing the nature of the lake-shore where a tributary valley joins the lake; and, secondly, by noticing the trend of subaqueous contour-lines. With reference to the first of these, if a lake-basin be eroded by ice the erosion may or may not occur also along the lower part of the course of a tributary valley, thus giving rise to a bay, whereas if the lake be formed by damming a valley of aqueous erosion, the entrance of an important lateral valley of considerable depth ought to be marked by a bay. I believe that it has been stated that such bays do not, as a general rule, exist, and, indeed, they are now rare, as the bay is usually filled up by detritus brought down by the tributary stream and converted into a delta with a convex curve; but in such cases the original concave curve may usually be seen, as, for instance (to take marked cases), the alluvial flat extending up the Newlands Valley, which must once have formed a bay a mile in length, opening into the old lake which has now been separated by alluvium into Derwentwater and Bassenthwaite, also the alluvial flat of Netherbeck in Wastwater, that of Sandwick and Castlehowe Point in Ullswater, and of Troutbeck in Windermere, and others less prominently shown. Other bays have not been completely filled by alluvium, as, for instance, Pullwyke in Windermere, and Howtown Bay in Ullswater, and here the streams entering the bays are comparatively insignificant, and the deltas, though in process of formation, have not advanced very far.

The accumulation of *débris* on the floors of the lakes will tend to obliterate sinuosities of contour due to submerged river-valleys, if such once existed; but any single case of the existence

of such a river-valley will be sufficient to dispose of the ice-erosion theory of the formation of the lake in which it occurs. Now, Dr. Mill's observations furnish some very remarkable cases of sinuosities of contour, which it is extremely hard to explain on this theory. In Windermere he notices "a channel about 100 yards wide, which, commencing off Ferry Head, runs close to the west shore, and spreads out to nearly the full width of the lake at Storrs Point. This channel suggests the remnant of an old river-valley by its narrow and sinuous course." That it is difficult to explain as the result of ice-erosion will, I think, be admitted by anyone who examines Dr. Mill's map of Windermere; but I shall eventually give reasons for supposing that, although it is probably a remnant of an old river-valley, it has since been largely covered up by débris, and that the depression is due either to the incomplete filling of an old gorge by detritus, or owing to the greater shrinkage of the thick mass filling such an old gorge, than of the thinner deposits on the neighbouring shallows.* The sinuosities of contour lines pointing to the subaqueous prolongation of tributary valleys are still more difficult to explain on the ice-erosion theory, and are in accordance with what must occur if old river-valleys have been dammed up. An interesting case occurs at Howtown, at the top of the lower reach of Ullswater, where the short Fusedale Valley is continued down the lake, as shown by the apices of the V's of the contour lines including and above that of 100 feet, pointing up Fusedale.

In the case of Windermere, Dr. Mill observes that "two instances occur in which the isobaths down to 150 feet indicate branches or sublacustrine valleys running into the main depression. One of these is a deep channel passing through Pullwyke in line with the valley of the present stream, a remarkable instance of sedimentation not having yet effaced primitive structure. . . . The other instance occurs on the east coast, south of Ecclerigg Crag, where there is a sharp inflection of the isobaths, towards the north side of the square bay, which is bounded on the south by the Troutbeck delta. A similar, though less pronounced, inflection of the shallower isobaths is shown in the bay south of the Troutbeck delta, and it is possible that these may be indications of the primitive outline of the basin when Troutbeck entered a wide bay which it has now filled up, and the inflections represent the angles between the pyramid of river-borne detritus and the original wall of the basin." A glance at Dr. Mill's map of Windermere will show the strong probability of the correctness of his surmise in the case of Troutbeck. Pullwyke deserves fuller notice. The bay runs for half a mile westward, or at right angles to the axis of the upper part of the lake, and once extended twice as far, as shown by the alluvial flat extending up Pull Beck valley, of which valley the depression in Pullwyke is the subaqueous

* For similar instances above water see Marr, *Quart. Journ. Geol. Soc.*, vol. 1, p. 35.

prolongation. The beck has a short course, rising in an insignificant ridge which lies about two miles west of the lake, so that we can hardly suppose that this ridge formed gathering ground for a glacier which could scoop out the subaqueous depression in Pullwyke Bay. This depression, moreover, lies *at right angles* to the general direction of the ice coming from the fells north of Windermere, and we are driven to conclude that if the basin of Windermere was scooped out by ice, *it hollowed out a valley running at right angles to the direction of its course, and directly continuous with a pre-existing valley lying immediately to the west of it!*

The three furrows running down Derwentwater are probably, as Dr. Mill suggests, due to the occurrence of eskers forming the intervening ridges. Such eskers occur in the neighbourhood, and the islands which lie on the ridges are composed of drift.

(2.) *Subaqueous Alluvial Flats*.—Three of the lakes sounded by Dr. Mill—Buttermere, Crummock, and Wastwater—are remarkable for their “flat-floored, trough-like form.” Buttermere “forms a simple trough, with steeply-sloping walls, and a nearly flat floor.” Its greatest depth, 94 feet, is less than one-sixth of a mile from the head, and here “is a nearly rectangular plain, measuring 400 yards by 300 yards, the undulations on which nowhere exceed 4 feet, and that not in abrupt steps, but as a nearly uniform slope from one end to the other, the gradient being about 1 in 300. Crummock is 144 feet deep, and of its floor “208 acres lie below 125 feet, forming a plain $1\frac{1}{2}$ miles in length, the lowest part of which is only 19 feet deeper. . . . From this flat plain the sides rise steeply—in some places they would be almost unclimbable if in the air—on both sides.” In the case of Wastwater the part below the isobath of 250 feet, forming a “plain one mile long, and almost a quarter of a mile wide, undulates into one gentle dip of eight feet to the deepest soundings of 258 feet, which occurred in several places. Wastwater deprived of water would present a singularly impressive appearance, with its steep wall of scree frowning above its long, level, central plain.” Coniston also possesses a plain, though not so marked as in the case of the three lakes just noticed.

These plains can hardly be due to glacial erosion, and certainly suggest deposition, which may have occurred before or after the filling of the lake. If they are caused by sediment accumulating in the lake, it is difficult to see why similar plains are not present in all the lakes, and their appearance is most in accordance with that of alluvial flats, formed in portions of old valleys before they were converted into lakes, and covered up fairly uniformly with a thin covering of sediment, and, possibly, of glacial débris, filling up the original river channels which

meandered through them. The sudden change from steep slope to flatness, in the case of Crummock especially, is more suggestive of such an origin than of lake-deposit. (See Dr. Mill's longitudinal section through Crummock, showing abrupt change from the delta slope to the flat floor.)

(3.) *Subaqueous Cliffs*.—Cliffs of exceptional steepness are recorded by Dr. Mill in Crummock, Ennerdale, and Wastwater. In the case of Crummock, "at Hause Point, on the right, the cliff ran sheer down, 70 feet being found 8 feet off the rock" (the italics are mine), "and the whole slope averaged 1 in 1, or an angle of 45°; while that on the opposite side was scarcely less, if we reckon from a depth of 25 feet instead of from the actual shore. Here, in a total breadth of 500 yards, there is a plain 300 yards wide, with no diversities of level exceeding 5 feet, and averaging 130 feet below the surface. The slope of the sides at these points is as steep as any of the precipitous mountain cliffs which surround the lakes." In the case of Ennerdale "we find that the subaqueous slopes are quite comparable with those of the free hillside for steepness." Dr. Mill took detailed sections of exceptional slopes in Ullswater, and gives a figure of them (*loc. cit.*, Fig. 17) in his paper. "Two sections were made from the rocky point opposite the delta" of Glenridding Beck. "These slopes are almost exactly 83° in the first 6 feet," measured outward from the shore, that is, *a sounding taken 6 feet out from the shore gives, in one case, a depth of 44, in the other a depth of 48 feet.* I do not know whether any advocate of glacial erosion will claim Ennerdale and Ullswater as "ice scratches," having almost vertical sides of 70 feet in one case, and nearly 50 feet in the other.

(4.) *Roches Moutonnées*. These rounded rocks are stated to give unerring indications of the direction of the ice when possessing a rounded, polished, and fluted appearance on one side, and a rough one on the other; and in such cases it is agreed that the rough side owes its character to having escaped erosion. As these rounded rocks usually have a small base, it is evident that much material has not been removed, when they are rough on one side and ice-worn on the other. But this practically implies that there has been but little ice-erosion in nearly all the upland valleys of Lakeland where this type of rounded rock is traceable, not only down to the heads of the lakes, but also along the sides down to and below water level, and *even on the rocky islands*. This character is specially noticed by Dr. Mill, in the case of the islands of Ullswater. He says: "The rocky islets all bear clear marks of ice-action, being smooth and striated, with gently-rounded curves toward the south, where the ice markings remain more distinct under water than on the dry surface. The northern sides of the islands show rough, angular fractures, indicating the advance of ice from the south." I have observed the same

feature on the islands of Windermere, but it is particularly important in the case of Ullswater, as the rough side is that which is away from the prevailing winds, and the roughness has not therefore been occasioned by subsequent erosion of a once-glaciated rock-surface. Ward felt the difficulty presented by the Windermere islets to the advocates of the ice-erosion theory, and remarked that "it is not quite clear why the islands at the centre of Windermere should have been spared by denudation to divide the present lake into two basins, since, so far as I can learn, there is nothing in the superior hardness of the rocks at that spot to explain it. It is the case, however, that just in that neighbourhood the valley widens somewhat; and thus, perhaps, the ice was enabled to spread laterally; while we may reasonably suppose that the islands represent only the degraded stumps of rocky hills which stood well above the valley-bottom in pre-glacial times." Difficult as the case of Windermere is to explain on the ice-erosion theory, that of Ullswater is still greater. House Holm, for instance, has a depth of 150 feet within about $\frac{1}{2}$ mile of its south-western end, and a depth of 175 feet in the same distance from its north-eastern end. In other words, if the ice eroded the basin of Ullswater, it must have removed at least 150 feet of rock in one place, practically none an eighth of a mile lower down, and 175 feet an eighth of a mile still lower down; although there is no important change in the character of the valley to account for the difference. If students of the physics of ice-motion assure us that this is possible, I, for one, shall be greatly surprised!

These islands are readily explicable on the supposition that the lakes occupy river-valleys which have been dammed. If we dammed up the higher part of Borrowdale, Castle Crag would form an island in the middle of the valley, and, as Mill points out, if Ullswater were 100 feet higher, Hallin Fell would stand out as an island a mile in diameter.

To sum up this part of our inquiry: The subaqueous scenery of the lakes presents several difficulties, on the supposition that they were formed by ice-erosion. Each of these difficulties may not be absolutely fatal to the theory in itself, but taken together they seem to me to furnish a mass of evidence which cannot be got over. On the contrary, the scenery can be readily accounted for on the supposition that the lakes are due to the damming up of river-eroded valleys, which have had a certain amount of material deposited upon their floors both before and after the process of conversion into lakes, and no single observation which has been made by Dr. Mill, so far as I am aware, is antagonistic to this view; indeed, they all harmonise perfectly with it. If we exclude the theory that the lake-basins were produced by ice-erosion, we are driven to adopt that of the blocking of river-valleys by solid rock or detritus, and to discuss the likelihood of

the Lakeland basins being due to a barrier produced by one or the other kind of material. I may here state that I commenced the study of the dams and lakes of Lakeland in hopes of showing that the lakes were due to the existence of rocky barriers, due to differential earth-movement, and was reluctantly compelled to give up this view after more detailed study. Unfortunately, the absence of deep borings deprives us of any direct evidence as to the nature of the barrier, but I have gathered together a considerable amount of indirect evidence which will, I think, render it more probable that the lakes are held up by superficial accumulations rather than by solid rock. I am aware that the difficulties in the way of this explanation were, twenty years ago, supposed to be very great. Clifton Ward, for instance, speaking of Wastwater, says that the presence of a moraine "does not explain the formation of the deep rock-basin, unless we could suppose that this groove, 40 feet beneath the sea-level, ran right on to the sea coast, and was now wholly filled up with drift, with the exception of the present site of Wastwater, the drift deposit being more than 250 feet thick near the lake-foot—altogether a supposition highly improbable. Hence I think we may conclude that this lake is not *due* to the presence of a terminal moraine."^{*} Before giving special arguments as to the nature of the lake-barriers, I may comment upon the asserted improbability of the existence of deep valleys filled with drift for several miles of their courses. In the case of land-ice issuing from mountain regions to flatter land, we may expect the transportation to be greater in the mountain track than on the plain track, where the gradient is generally less, and the ice can expand laterally; consequently a greater deposition of drift in a valley traversing a plain than in one traversing a mountain region is very probable; and, indeed, there may be no deposition to speak of in parts of the mountain region, and much in the plain. Or a mountain area standing out from a shallow sea, may have its valleys kept free of drift, whilst the submarine extension of these valleys may become partially or entirely blocked with drift.

The deposition of more drift in one part of a valley than in another, causing small lakes in the case of mountain-tarns, has been discussed by me elsewhere, and the formation of lakes in the same way is only a question of degree. Now, what evidence is there of the formation of great masses of drift by ice? As regards thickness, one of the best cases is the stratified, probably submarine drift, now raised up to form the Chaix Hills, rising through the Malaspina Glacier of Alaska.[†] Russell states that these hills "are composed of stratified morainal material," and that "it is evident that the minimum thickness of the deposit cannot be less than 4,000 or 5,000 feet." In our own country

^{*} *Quart. Journ. Geol. Soc.*, vol. xxxi, p. 159.

[†] I. Russell, *U.S. Geol. Survey*, 13th Annual Report, p. 257

we find that Scarborough is situated on a drift-filled valley, the base of which is not seen, but the drift rises to a height of 171 feet above high water near the Spa.* Whitaker describes a case of an old filled-up valley occurring below the present Cam Valley, at Newport. Here, "after boring to a depth of 340 feet, the work was abandoned without reaching the Chalk, the Drift in this case reaching to a depth of about 140 feet below the level of the sea, though the place is far inland."† One of the best instances of a drift-filled valley, however, occurs in the outskirts of the Lake District itself, and is recorded in the memoirs of the Geological Survey.‡ At Park House Mines, in the Furness District, situated about 75 feet above sea-level, one bore gave a depth of 306 feet of drift, another of 369 feet, and another of 537 feet before reaching the solid rock. We have here an indication of a buried valley at least 450 feet below sea-level. Now a depth of 76 fathoms is the greatest depth met with in this latitude between England and Ireland, though there are several indentations of the 20-fathom line here and southwards, indicating the seaward extension of partially-filled valleys.§ The Park-boring must have struck a valley filled with drift or marine deposits, or both, for many miles from the point at which it was struck in the boring. This valley is filled with drift to its head; had it extended towards the heart of the district, its upper part might have been filled with a lake rivalling in size and depth any of those actually met with. It would appear therefore that there is really no difficulty in supposing valleys filled with drift along a course of many miles, and to a depth of several hundred feet.

Judging from the behaviour of what Russell terms piedmont glaciers, of which the Malaspina glacier furnishes a good type, we might well expect the sea-floor lying west of Scotland, Western England, and Wales, to be thickly covered with drift deposits, which would account for the greater depths of depressions lying near the mountains than of those situated further away, though of course this might also be produced by differential movements.

Passing on now to consider special cases of lakes, it may be noted that I brought forward evidence to show that the Lake District tarns were produced by the formation of drift dams across valleys, || and later ¶ that a sheet of water, Hayeswater, described by Mill as intermediate between a tarn and a valley lake, was due to the same cause. If it can be shown that the larger lakes present features analogous to those furnished by the tarns, this will be strong evidence of their origin in a similar manner.

* Phillips, J., *Geology of Yorkshire*, Part I, third edition, p. 124.

† Whitaker, W., *Brit. Assoc. Report*, 1880, p. 588.

‡ Aveline, W. T., *Explan. Quarter-Sheet 91, N.W.*, p. 4.

§ See Map attached to Report of Committee to investigate the Marine Zoology of the Irish Sea; *Brit. Assoc. Report*, 1894, p. 318.

|| Marr, *loc. cit.*

¶ Marr, *Quart. Journ. Geol. Soc.*, vol. lii, p. 15.

Commencing with the smaller lakes, an alluvial flat which may well conceal a drift-filled valley extends between Grasmere (208 feet above sea level) and Rydal (181 feet), and though there is not a continuous stretch of alluvium between the latter lake and Windermere (130 feet), a somewhat hasty inspection convinced me of the probability of a drift-filled valley* occurring between these two lower lakes. Thirlmere, one of the valley lakes of intermediate size, had a depth of 96 feet near its head; and of 93 feet near its foot. It was† 533 feet above sea-level, and drained into the St. John's Valley, but the stream flowing from it approached within a few score yards of the alluvial flat of the Naddle Valley, the watershed on which the hamlet of Smaithwaite stands being only 120 feet above the former level of the lake. The Naddle Valley is filled with drift and alluvium for a long distance below Smaithwaite; indeed, the drift extends to its junction with the Derwent. The low watershed (apparently of drift) between these two valleys is remarkable, but is easily accounted for on the supposition that the Thirlmere River originally drained down the Naddle Valley, but when the latter became filled with drift, the lake was formed to the level of the col, formerly separating the Thirlmere Valley from the Vale of St. John.

Taking the larger lakes in order, we may commence with the Derwentwater-Bassenthwaite pair, which are generally admitted to have been once united. Derwentwater is elevated 245 feet above sea-level, and has a maximum depth of 72 feet, whilst the altitude of Bassenthwaite is 224 feet, and its greatest depth 70 feet. The present river issues from the north end of Bassenthwaite, and after flowing northwards for a short distance, turns sharply to the west. About half a mile south of the present exit, Dubwath Beck enters Peelwyke from the west; it is a mere runnel, rising in a drift col a few feet above the present alluvial flat, a short distance west of Embleton Station. Beyond this drift col, another small stream, Tom Rudd Beck, flows towards Cockermouth, occupying a drift-filled valley, mostly covered by alluvium. The drift col between the two streams is obviously a recent product, whilst the valley itself (the Embleton Valley) is a wide and important valley, which must have been formed by a considerable body of water. It is difficult to explain the existence of the two valleys (the present Derwent Valley and that of Embleton) diverging from the Bassenthwaite depression, except by supposing that the drainage of the Derwentwater-Bassenthwaite system once went through the Embleton Valley, and that when this was blocked by drift, the lake was formed up to the level of the present outlet, and the overflow carried off by the present Derwent. It seems probable

* For use of term "drift-filled valley" see Marr, *Quart. Journ. Geol. Soc.*, vol. li, p. 32.

† I use the past tense, as this lake has been artificially altered by the Manchester Waterworks Company.

that some of the material for the barrier was supplied by the Scotch ice, and in this connection it is interesting to note that the Sale Fell minette boulders have been carried southwards.

The Buttermere-Crummock pair of lakes lie S.W. of those last mentioned. Buttermere is 331 feet above sea-level, and Crummock 321 feet, the greatest depth of the former lake being 94 feet, and of the latter 144 feet. The river Cocker flows over solid rock shortly after its exit from Crummock water, but talus and peat occur between High Wood (about one-third mile S.E. of the exit of the Cocker from the lake) and Lanthwaite Beck, which flows north through a probably drift-filled valley, now covered by alluvium, and joins the alluvial plain of the Cocker about a mile to the north, the watershed between the lake and Lanthwaite Beck being less than 200 feet above the lake-level.

Loweswater, 429 feet above sea level, discharges its surplus waters into Crummock by Park Beck. It is of interest as being the only lake in the district of any size which drains towards, and not away from, the head of the district. At the head of the lake a stream runs, which flows from a col about 100 feet above the lake level; another stream flows northward from this col to join the Marron River. The drainage of a stream flowing from Floutern Tarn through one of the many Mosedales is somewhat eccentric. It runs through Mosedale in a general northerly direction, and looks as though it should flow through Loweswater, instead of which, on reaching the depression in which Loweswater is situated, it runs off at an angle of 290° from its former course to flow into Crummock. The somewhat remarkable behaviour of this stream may be readily accounted for, if we suppose that it once flowed northward and north-westward through the Loweswater Valley to join the Marron River; and when the Loweswater Valley was blocked by drift to a height greater than that of the watershed separating the Loweswater Valley from that of Crummock, the drainage was switched off into the latter valley. I have not yet examined the col at the upper end of the Loweswater Valley, but hope to do so ere long, and feel convinced that it will be found to be a drift-covered col.

Ennerdale, 368 feet above sea level, has a maximum depth of 148 feet. The Ehen issues from it through an alluvial tract, and flows a little south of west towards Cleator Moor, where it turns abruptly south, and enters the sea at Sellafield. The drainage of the streams on the west side of the Lake District presents many apparent anomalies, which can be explained on the supposition that their courses have been diverted owing to the thick accumulations of drift spread over this western low ground. The Ehen probably entered the sea near St. Bees, at one time, and owing to the filling up of the valley over the plain by drift, that

part was directed southward, though it still flows over its original site for some miles below the end of the lake.

Wastwater is about 200 feet above sea level, and its greatest depth is 258 feet. Its deepest part is thus below sea level. Two apparent anomalies in the drainage of the region are noticeable; Countess Beck appears to enter the lake about half a mile from the foot, and also to enter a river at the other end. I have not carefully examined this tract of recent years, but my recollection is that a drift-filled depression runs along the course of Countess Beck past a small tarn to join the Irt (the river issuing from Wastwater) near Kidbeck. Shortly below this the river Bleng, a tributary of the Irt, joins the main river, after a very remarkable course. For about six miles from its source the Bleng flows in a south-westerly direction to within a short distance of Gosforth; it then turns back almost parallel with itself, and so flows into the Irt, which presently turns south-west once more, so that the waters of the Bleng and the Irt below it flow in a sharp S. Near Gosforth the Bleng is about three miles from the sea, and separated from it by no very high ridge. The apparent anomalies can be readily explained if we suppose that the Wastwater Valley, once drained by Countess Beck, passed Gosforth to the sea, and was joined by the Bleng. The filling of the valley by drift would cause the filling of the Wastwater depression to the level of the present exit, and the diversion of the drainage of the Bleng at right angles to its former course.

Coniston is 143 feet above sea level, and has a maximum depth of 184 feet, so that portions of this lake also are below sea level. I have not examined the course of the lake which issues from its foot in recent years, but according to my recollection of it, it runs through a marshy valley with no rock-exposures until it falls into the Leven Estuary. In this case the lake may be simply due to the filling up of an ancient valley to a higher level (that of the present exit, or a few feet above it). The maximum of drift required would be about 200 feet.

Windermere has a surface 130 feet above sea level; its maximum depth is 219 feet. This lake, and the two just considered, are the only ones in the district the lowest parts of which are below present sea-level. The foot of the lake forms a sigmoidal bend, from which the River Leven flows through a rocky valley, flowing south-west to the estuary. The depression of the Windermere Valley is, however, continued due south to the Cartmel Valley, which is one of considerable importance, though drained by a mere runnel. The col between the lake and the Cartmel Valley is very little elevated above the level of the lake. I recently followed this valley past Cartmel to the sea, and found that it might well be drift-filled all the way from the foot of the lake to the sea. Many peat-mosses exist along this line,

indicating the former existence of a number of lakelets in drift-hollows.

Haweswater is 694 feet above sea-level, and has a maximum depth of 103 feet. As far as I recollect, drift occurs down the present valley, either along the course of the stream or near to it, until it joins the Lowther, and this river also shows no rock in its course for some distance below Bampton.

Ullswater is 476 feet above sea level, and has a maximum depth of 205 feet. The Eamont, which issues from its foot, flows, as far as I am aware, through a drift-filled valley, mainly overlain by alluvium, to its junction with the Eden.* The latter river flows through alluvial flats until it reaches the gorge commencing below Little Salkeld, where the first rock is seen in the bed of the stream, at a height of about 270 feet above sea level, or about 100 feet lower than the deepest part of Ullswater. This lake may well have been formed by the filling up of a river-valley with drift for some distance below the foot of the lake, in which case the present Eamont is flowing at a higher level along a course situated approximately above that of the pre-glacial stream. It is by no means certain, however, that the Eden ran through the Little Salkeld and Armathwaite gorge in pre-glacial times, and it is possible that it ran through a valley to the west of this, now largely filled with drift, though the existence of this western valley is not necessary for the formation of Ullswater by a drift barrier.

In the above portion of my paper it has, I believe, been shown that the filling of valleys by drift to a considerable depth, and for many miles of their course, is by no means improbable; that all the valley lakes of Lakeland are connected with valleys so filled with drift as to render it possible that these drifts form barriers sufficient to account for the existence of the lakes.† Until the existence of the drift to a sufficient depth to form the required dam is disproved, the existence of rock-basins in Lakeland cannot be unhesitatingly asserted by anyone.

Further than this, there are certain apparent anomalies in the distribution of the present drainage in the case of all the larger valley lakes, except Ennerdale, Coniston, Haweswater, and Ullswater, which are not actually incompatible with the theory of glacial erosion, nor with that of differential uplift, but which receive a more satisfactory explanation upon the view that they are due to blocking of valleys with drift. Again, the drift occurs in these valleys where it ought to be found, if the lakes were formed in this way; moreover, the apparent anomalies in the distribution of the drainage connected with the larger lakes are exactly comparable with those which occur in the case of the tarns,

* The old valley lies somewhat north of the present stream, near Edenhall.

† It will be seen from the text that I have not examined all the valleys below the lakes in detail, but have examined several carefully, and, all except that at the N.W. end of Loweswater, with some degree of care.

as to the formation of which by drift dams I have given evidence elsewhere. I can find no real distinction between tarns and valley-lakes, and a transitional series, such as Hayeswater, Devoke Water, Rydal, and Grasmere can be traced.

There is one difficulty in the way of this explanation of the lakes, the consideration of which I have reserved until now, namely, that many of the lakes are deepest near the head. Of the large lakes we find that this is the case with the following : The Derwentwater-Bassenthwaite Lake, Buttermere (though, if we treat Buttermere and Crummock as one, this is not the case, Crummock being deeper than Buttermere), Windermere, and Ullswater. Wastwater is deepest about the centre, Haweswater and Coniston near the centre, and Ennerdale alone nearer the foot. In the case of Windermere we require a dam sloping gently from the mouth to the present head. The difficulty appears greater than it really is, for the present head of most of the lakes is some distance below the original head, owing to the cutting down of the outlet, and the filling up of the head by alluvial material; thus Ullswater and Windermere probably extended very much higher up their valleys than they do now, whilst the deepest parts of the Derwentwater, Bassenthwaite, and Buttermere-Crummock areas may originally have been beneath the alluvial tracts which now separate the lakes, due to the large lateral valleys which enter the main valley opposite to them. The difficulty is further diminished, if it does not disappear, when we remember that much of the glacial drift which borders the Lake District was not derived from the centre of the district. The existence of boulders from the north on the north-west sides of the district, and also on the east side, in the Eden Valley, indicates that much of the material laid down on those comparatively flat tracts had a northern origin, and this material would block Ullswater and Haweswater on the east, Bassenthwaite and Crummock on the north, and Ennerdale and Wastwater on the west. Again, the drift in Morecambe Bay, coming from the north-east, would furnish material for stopping up the Windermere and Coniston valleys. This material would naturally be washed towards the centre of the district, and gradually thin away in that direction, in the form of "kettle-drift," enclosing hollows and sinuous channels like those found in Derwentwater, Windermere, and other lakes.

I had hoped at one time to be able to show that the lakes were due to the settling down of the central dome of the district, and the formation of barriers owing to the production of a ring of rock by a "creep" process, at points about equidistant from the centre of the district. The idea was a fascinating one, but the evidence I have gathered does not appear to be in favour of it. Earth-movements must have occurred, if the lake-basins were not hollowed by glacial erosion. The existence of tracts of lake-floor

below sea level in Windermere, Coniston, and Wastwater requires this, as also the great accumulation of drift at Park House Mines in the Furness District, but this movement appears to be one of widespread depression, as indicated by other evidence in the form of buried valleys, etc., elsewhere. As to the date of this depression we have not much evidence. It was probably pre-glacial, and may have been of Pliocene date, but the actual period of its occurrence does not much concern us in connection with our present inquiry. Nor is it of much importance whether the drift material which, according to my belief, formed the dams which ponded back the waters of our larger lakes, was accumulated by land ice or by floating ice, or by a combination of the two, though I have elsewhere given some of my reasons for adopting the views of those who are most competent to speak of the glaciation of the district, that it was largely the product of terrestrial glaciation. If the drift dams are there we yet await the evidence which will convince us that the lakes of Lakeland are held up by rocky barriers; and even should this prove to be the case, I feel convinced that the valuable detailed observations of Dr. Mill show that the rocky barriers were not produced by erosion in places higher up the valley, but by differential earth movements.

I should like to add in conclusion that geologists are deeply indebted to Dr. Mill for his painstaking work, and that I myself am very grateful to him for the interest he has taken in geological as well as in purely geographical questions connected with the water areas of Lakeland.
