With the author's kind regards.

12.

Recd Dec 26. 1873
Read before sent off to
the Press. A very good
paper. but it will not
do to draw conclusions
from local observations
Since I went round
Arran seeking the
ice cap I have been
driven out of my
own theories.

12.

[*From the* Quarterly Journal *of the* Geological Society *for* *August* 1873.]

THE GLACIATION

OF THE

NORTHERN PART OF THE LAKE-DISTRICT.

BY

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OF THE GEOLOGICAL SURVEY OF ENGLAND AND WALES.

[Plate XV.]

Contents.

I. Introduction.

The district to which the following paper relates, belongs to the northern half of the English Lake-country. The observations now laid before the Society, with the leave of the Director-General of the Geological Survey, have been collected during the past three years while engaged in the official examination of the geology of the district. The area (map, Pl. XV.) is for the most part included within the one-inch Ordnance map 101 S.E. It contains four large valleys immediately north of the main watershed of the country, three of which, the vales of Thirlmere, of Borrowdale, and of Buttermere and Lorton, drain northward; the fourth, the vale of Ennerdale, drains westwards. Another, the vale of Keswick, drains westward also, including under this head the country between Mell Fell on the east, and Bassenthwaite Lake on the west. The western side of the Ullswater Valley, draining north-eastward, comes in at the south-east corner. All geologists admit the fact of the glaciation of the district in question; and many notices of the same have been published. It has been my privilege to collect details upon the subject, an *outline* of which I have now the honour of submitting to the Society *.

II. Leading Questions suggested.

The fact of the glaciation being granted, several questions at once suggest themselves.

1. Did the glaciating agent work from north to south?
2. Did it come from within or without the district?
3. Was this agent floating ice, a system of local glaciers, or an unbroken ice-cap?

There are two main sets of observations directly bearing upon these questions:—(1) The direction of the ice-scratches; (2) The direction in which the boulders have been transported.

It will presently be shown in detail that the direction of the former has reference in a *general* way to the valleys in which the groovings are found. And that of the latter, the transport of boulders, can only be learnt by an accurate knowledge of the solid geology of the district. A few words must therefore be said upon this point.

A line drawn from the upper end of Ennerdale Lake, through Honister Crag, along the east side of Derwent Water, and across the lower end of St. John's Vale to Mell Fell, will divide the map (Pl. XV.) diagonally from S.W. to N.E. On the N.W. side of this line lie the Skiddaw Slates, on the S.E. side the volcanic series of Borrowdale. No two sets of rocks could be more utterly unlike each other. On the one hand, old mud rocks, much contorted and cleaved, of a blue-black colour and usually soft, though containing some harder sandy beds; on the other hand, alternations of ancient lava and ash beds, gently rolling in large curves, in some cases cleaved, and for the most part hard. In the north of the district, about Skiddaw, granite and metamorphosed Skiddaw slate occur—rocks of considerable hardness and distinctive appearance.

If, then, the glaciating agent worked in the main from north to south, we should expect to find boulders of Skiddaw Slate, Skiddaw Granite, and the metamorphic rocks associated with it, upon the area occupied by the volcanic series; if from south to north generally, we ought to find boulders of the volcanic series upon the Skiddaw-Slate area. The fact is this. Over the district under consideration, not one boulder of Skiddaw Slate, Skiddaw Granite, or the associated metamorphic rocks, has been found upon the area occupied by the volcanic series; while boulders of the volcanic rocks occur in thousands over a large part of the Skiddaw-Slate area up to certain heights.

* All the minor details of the subject are necessarily reserved for publication in a forthcoming Survey Memoir.

Moreover, among the transported blocks, there are not found any of rocks foreign to the district as a whole. Hence, I think, we may conclude—

1. That the glaciating agent did not work in the main from north to south.

2. That the ice did not come from *without* the district.

It may be objected to this that any effects produced by a great northern ice-cap passing over the district were effaced by the subsequent local glaciers; but I cannot think that this is very probable; surely some foreign boulders would have been left; at any rate, the burden of proof lies with the advocates of this great mountain-ignoring ice-cap.

The third question, just referred to, namely the part played by floating ice, local glaciers, or sheet-ice in the work of glaciation, can only be answered by a careful consideration of the facts. These may be dealt with under the following heads:—

Direction and height of the ice-scratches.

Moraines and boulders.

Drift deposits.

III. Direction and Height of the Ice-scratches.

The general directions of the scratches will be seen at a glance in the accompanying map (Pl. XV.); and only a few words of explanation must be given for each principal valley.

1. *Borrowdale.*—From the upper end of Derwent Water to the higher reaches of Borrowdale the rock-groovings are very numerous. It will be seen that the scratches follow mainly the direction of the several valleys in which they occur, and the direction upon some of the mountain-ridges or tablelands between two *parallel* valleys is the same as that of the valleys. For instance, a great series of N.N.W. and S.S.E. scratches is found ranging from Ullscarf (1) to the head of Derwent Water, at all heights from a little over 2000 feet downwards; these point straight down the Watendlath Valley, and pass completely over the Watendlath and Grange Fells with a very uniform direction. The ridge separating Greenup Gill from Longstrath is likewise crossed by scratches taking the direction of the valleys on either side; and some occur at a height of 1750 feet. Rosthwaite Fell, just north-east of Glaramara (2) forms the western side of the Longstrath Valley; and while many scratches are found to run with the latter, there are some few crossing the Fell above in a N.N.W. direction at a height of 2000 feet.

On the western side of the Derwent, wherever a side combe or valley opens into the main one, sets of tributary groovings join the main-valley series, as from Sourmilk Combe above Seathwaite, from the valley between Seatoller and Honister Pass, and the steep little valley just north of High Scawdel. It is to be noted however, that the main-valley scratches pass over the Fell between the plumbago-mine (just above Seathwaite) and the valley leading up to Honister Pass. North of Grange, the scratches are almost wholly confined to heights below 1000 feet, with the exception of some at the north end of Castlerigg Fell, which have a N.N.W. and S.S.E. direction up to the verge of the steep Wallow Crag, and are at a height of nearly 1200 feet. On the eastern slopes of Cat Bells the scratches point slightly up and across the ridge.

2. *Thirlmere Valley.* — Here also the main direction of the scratches is that of the valley and its tributaries. They are not very frequent on the steep western flanks of the Helvellyn range, but occur every here and there from 2500 feet (in Browncove) downwards. The scratches over Armboth Fell run in the same direction as those in that of the Watendlath valley, and evidently belong to the same series. The extensive tableland around High Seat (1996 feet) seems free from any rock-groovings above 1500 feet.

3. *Keswick Vale and its smaller side valleys.*—But few scratched surfaces are to be seen in this wide valley; this is in part due to the covering of drift, and in part to the splintering character of the Skiddaw Slate. All the scratches hitherto mentioned, with but few exceptions, occur among the rocks of the Borrowdale volcanic series, which, being harder than the Skiddaw Slate, *generally* retain the markings better. In Keswick Vale, out of nine instances of scratched rocks, three are found upon small bosses of greenstone intruded among the slate.

A few cases of scratches occur along the southern flanks of Blencathra, the direction being with the mountain-side and below 1000 feet. Others are found on either side of Bassenthwaite Lake, where the valley is narrowest. Down the tributary valleys of Newlands and Coledale, sets of scratches also run, following the direction of the valleys.

4. *Buttermere and Lorton Valley.*—On Fleetwith, behind Honister Crag, there are many scratched surfaces from 1750 feet downwards; and in the combes and glens joining the main valley they occur above 1000 feet, and sometimes as high as 1750 feet. But the main-valley scratches are seldom to be found on the mountain-sides above 800 feet, with the exception of a case upon the flanks of Grasmoor, where the height is rather over 1000 feet.

At the southern end of Mellbreak (20), the direction seems to part on either side the mountain; and again at the northern end of Crummock Water, where one set of scratches points straight down the vale of Lorton, and another set runs parallel with Loweswater.

5. *Ennerdale.*—The scratches are less numerous in this valley owing to the large amount of fallen material hiding the steep mountain-sides. Besides some few cases of scratches following the direction of the main valley, below 1000 feet, there are many pointing down the hill-side out of the various combes beneath Pillar (24) and Haycock (25), and down the northern flanks of Kirk Fell (23), some of which are at a height of more than 2000 feet.

6. *Ullswater Valley* (western side of).—Several large valleys run eastwards from the lofty Helvellyn range to join the main valley

in which the lake lies. Each of these has at its head one or more combes, sometimes containing a tarn. Scratches may be found pointing out of each one of these combes, and many others down the lower parts of each valley. In several cases, however, there are also scratches with a direction more or less across the ridges parting valley from valley. Thus, a long narrow ridge separates the valley in which Brothers Water lies from Deepdale; and scratches run directly across the ridge to a height of over 1500 feet. The ridge next to the north also, between Deepdale and Grisedale, is crossed in a similar manner at heights up to 2000 feet below Gavel Pike (37), while Annstone Crag (38) (the north-eastern end of this same ridge) is grooved over its summit (1423) in a N.W. and S.E. direction. The eastern end of the Striding Edge ridge, between Grisedale and Glenridding, is also crossed obliquely by scratches up to a height of 1750 feet.

IV. Moraines and Boulders.

1. *Various kinds of moraine-like mounds.*—Before alluding to the moraines in any detail, it is necessary to say a few words upon the different kinds of moraine-like mounds, as the determination of moraines is not always the easy thing it would at first sight seem to be. The following various kinds of mounds may be distinguished:—

a. True glacial moraines, of a more or less elongated form, though often much cut up by stream-courses, and made up of large and small angular or subangular blocks, some of which are scratched, imbedded in a clayey or sandy matrix; transported blocks of considerable size often lie on the top.

b. Mounds of very similar constitution to the last, formed by the cutting up of an up-valley drift plateau by numerous stream-courses.

c. Mounds of subangular stones and wash, formed where mountain-streams, either occasional or constant, open out into a main valley.

d. Mounds formed by ice-rounded rocks covered with a thin coating of moraine-material or drift.

e. Mounds formed of stratified and false-bedded sand and gravel, quite free from large boulders within, yet frequently having some strewn upon their top.

f. Mounds of scree-material formed at the bottom of a slope, by the sliding of fragments over an incline of snow lying at the base of crags. (I am indebted to Mr. Drew, late from Cashmere, for this suggestion, he having seen mounds of this kind at the foot of snow-slopes among the Himalayas.)

2. *Moraines.*—Very little need here be said about the moraines proper. Most of them belong to the latest set of valley-glaciers, and are confined to the higher parts of the district and the upper ends of large valleys. There is no instance of an undoubted moraine *upon* any of the spreads of drift presently to be noticed, though in some few cases they are found coming down to the borders of this

drift where it attains some elevation. A case in point is the well-marked semicircular moraine beneath the partial combe formed by Wolf Crags, on the southern edge of Matterdale Common, where the base of the moraine and the upper limit of the drift are at a height of 1350 feet. Perhaps the finest examples of large series of moraines are to be found at the head of Ennerdale, up Greenup Gill, and in Longstrath, though they occur more or less in the upper reaches of every valley, and even upon the summit of many watersheds where the ground along the watershed is much higher on either side.

3. *Boulders.*—The *general* transport of boulders from south to north of the district has already been alluded to in opening the subject of this paper. Blocks of the volcanic series of Borrowdale have been carried in immense numbers northwards and north-westwards down the principal valleys on to the area occupied by the Skiddaw Slate. Just an outline only must now be given of some of the special cases of boulder-distribution.

On either side the lower end of St. John's Vale occur masses of a peculiar syenite, fragments of which are readily recognized. Boulders of this rock have been carried in immense numbers eastward towards Penrith; they may be found up to a height of above 1250 feet on Mell Fell and Little Mell Fell, and on the lower parts of the sides of Blencathra. Boulders of the same rock have also been carried westward, *down* the vale of Keswick; and some few occur on the summit of Latrigg, 1200 feet. Further down the vale none are found on the *south-western* side of the Derwent.

Crossing the Thirlmere Valley, between Armboth and Helvellyn, is a very distinctive dyke of quartziferous felspar-porphyry. Boulders of this rock have been carried into the Keswick Vale, and then distributed both to the east and to the west; some of these also occur on the summit of Latrigg; but further west they are not found higher than 800 feet, and are confined to the northern side of the vale.

A large tract of syenite, quite distinct in appearance from the St. John's, stretches from near the N.W. corner of Buttermere Lake over to Ennerdale and south of it. Blocks of this rock are thickly strewn all down the vale of Lorton to Cockermouth, sometimes too at considerable heights, as for instance on Mellbreak (20) (Skiddaw Slate) at above 1500 feet, on Fellbarrow (35) at 1363 feet, and on the southern flanks of Kirk Fell (31) (that Kirk Fell N.E. of Lorton) at 1100 feet. They are far more numerous also on the west side of the Cocker, north of Lorton, than on the east side. A very large number of syenite blocks have also been carried down the Ennerdale valley into the open country beyond.

Up the valley of the Glenderaterra, between Skiddaw and Blencathra, there occurs a small patch of granite and a large tract of hornblende-slate surrounding it. Boulders of the granite (which is white, with black mica) may be traced southwards to the mouth of the valley; and every here and there a boulder has been detected *westward* down Keswick Vale along the foot of Skiddaw, one being found upon the summit of Latrigg. The hornblende-slate boulders are more numerous and seem to have been carried for the most part westward, a good sprinkling being found upon the summit of Latrigg, and upon the fell-side behind Latrigg up to 1250 feet, also further down the valley on the *north* side up to 800 feet.

Upon Sale Fell (1170 feet), on the west side of Bassenthwaite Lake, is a very small patch of intrusive rock of a peculiar character; boulders of it are found upon the north side of Kirk Fell (31) to a height of nearly 1250 feet, and upon the south side of the water-shed uniting Kirk and Broom (30) Fells up to fully 1250 feet; but none have been observed further south, or anywhere to the *north* of Sale Fell itself.

Lastly, with regard to the height at which boulders of the volcanic series are found upon the Skiddaw-Slate area. Upon Matterdale Common and the flanks of Mell Fell they occur up to a height of 1400 feet, on the southern slopes of Blencathra up to 900 feet, upon Latrigg up to 1200 feet, on the south-western slopes of Skiddaw to 800 feet. They are scattered over the whole mountain-group north of Whinlatter Pass up to 1670 feet; and along the eastern flanks of Grisedale and Causey Pikes (32 and 34) they occur *below* 1000 feet. Upon Maiden Moor (1887 feet) such boulders are found to the summit, and at intervals all along the ridge to the extremity of Cat Bells (5). At one spot, however, called Hause Gate, the lowest between Maiden Moor and Cat Bells, they are specially abundant.

Boulders of the volcanic series are plentiful along the east side of the Buttermere and Lorton Valley up to 800 and 900 feet; on the west side, they occur on Mellbreak (20) up to 1500 feet, upon Fell-barrow (35) up to 1360 feet, and at lower elevations.

On Starling Dodd (36—height 2084 feet), but little more than a mile due west from Red Pike (19—height 2478 feet) there are syenite boulders to the very top, the Dodd itself being altered Skiddaw Slate, almost surrounded by syenite *at a lower level*, except quite near the summit of Red Pike.

All over the area occupied by the rocks of the volcanic series, perched blocks of the same kind of rock are very numerous at all elevations up to considerably more than 2000 feet; but details of these cannot here be given.

V. Drift Deposits.

There are three different kinds of deposit in this district belonging to the Glacial Period.

1. *Till.*—Under this head I include patches or spreads of stiff clay stuck full of smoothed and scratched stones and boulders, and unstratified. It occurs every here and there in small patches among the mountains, in rock-sheltered spots, and may frequently be seen in the valleys either by itself or underlying a more gravelly deposit next to be noticed. In some few places the clay is free from stones and boulders.

2. *Drift-gravel.*—This consists of subangular gravel (very rarely

containing bands of sand) in a clayey matrix, with large boulders in and upon it. It sometimes passes down into the Till just described, and either forms sloping plateaux running up the valleys (as the Till alone sometimes does) or wide spreads of a more or less moundy appearance. This deposit is mostly seen in Keswick Vale, and may be traced in parts of the district to at least 1500 or 1600 feet in height.

3. *Sand and gravel.*—Every here and there, along or at the ends of the principal valleys, are mounds having very much the appearance of moraines, but formed of stratified and false-bedded sand and gravel, generally free from *large* boulders, and sometimes quite free from *any* angular blocks whatever, though large boulders almost invariably occur about and *upon* them. It will be necessary to mention a few instances of this deposit.

Some low moundy hills or "hows," as they are called, occur upon the east side of the Cocker, just where the Lorton Vale opens out into the low country. In a large pit by the side of the high road, half a mile north of Lorton, a deposit of sand and gravel is seen dipping S.W., or down the how-side at a high angle; the stones are well rounded; but there are *some* subangular blocks about one foot in length: the height above the sea is from 230 to 300 feet. Between Embleton and Bassenthwaite stations, just north of the line, is a deposit of false-bedded sand and gravel resting upon finely stratified sand with clayey bands, and containing no boulders or angular blocks; its height is from 250 to 300 feet.

At the ends of both the Naddle and the St. John's valleys are long mounds of stratified sand and gravel, with no large boulders *in* but some *upon* them. One of the St. John's-Vale mounds stretches straight across the valley from Bridge House to Hill Top, and has evidently been cut through by the stream. In one section, close by the beck, the sand and gravel deposit is seen to rest upon yellow clay with boulders at the level of the water; in another part a small pit shows coarse subangular gravel on 6 feet of fine stratified sand, its base not seen. In both valleys these mounds are at a height of 500 feet. Another instance of such mounds occurs at Beckces, a little west of Penruddock station; one pit gives 8 feet of sand (base not seen) with a little gravel on top, but free from boulders, though they occur on the surface; the height here is 860 feet.

Lastly, just south of Troutbeck Station and off the Ullswater Road (west of Mell Fell) there is a series of long mounds of stratified sand and subangular gravel, with some boulders within as well as upon the hillocks; they occur between the heights of 900 feet and 1045 feet; but, so far as can be seen by the help of the present pits, the contained boulders are larger at the 1000 feet elevation than at the 900 feet; this, however, *may* be due to accident. In the highest pit-exposure one very large boulder occurs; but it is surrounded by subangular stones in a clayey matrix and *may* be part of a later deposit against the bank of sand and gravel, which only contains much smaller boulders.

Such are the facts, under the heads of *ice-scratches*, *moraines*, *boulders*, and *drift deposits*. Ice in some form has had much to do with most of them; but in what form has it acted?

The direction of the ice-scratches, the way they run along with the main valleys, although sometimes systematically crossing low watersheds, at once suggests sheet or glacier ice originating within the district; floating ice would not produce this regular rock-grooving. The moraines, for the most part, bear witness to glaciers each confined to its own valley and of *late* date.

The boulders give evidence in two directions. First, it is evident that the direction in which they have travelled agrees with that of the uniform ice-scratches; and since these last seem due to a more or less general ice-sheet, there is presumptive evidence that many of the boulders have been moved onwards by the same. Secondly, there are some facts pointing to the transport of boulders in directions other than that of the ice-sheet, and into positions into which neither ice-sheet nor smaller glaciers could have carried them; this second class of facts points to the agency of *floating* ice.

With regard to the drift deposits, while the Till of the district probably represents a *moraine profonde*, the drift-gravel looks like moraine-matter and Till remodelled and partly rounded beneath water; and the mounds of stratified sand and gravel free from boulders seem to indicate currents of water meeting at certain points and forming sand bars when the climate was milder and there was no floating ice.

But before ice-sheet and floating ice can have their limits assigned to them, particular notice must be taken of what must have been the configuration of the land at various stages of submergence, and we must consider whether ice would be likely to float in certain directions or not.

VI. Land-contour at various Stages of Submergence.

In figs. 1–5 the land-contour is given at various points of submergence.

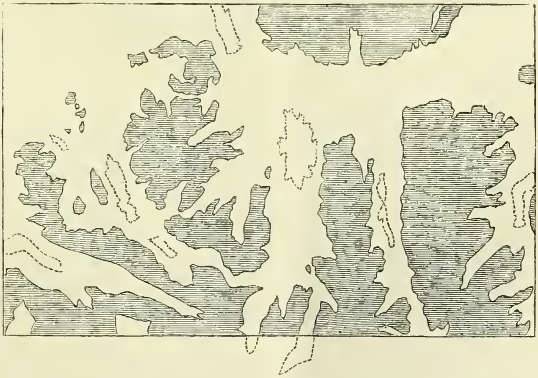
Fig. 1 shows that if the land were submerged to a height of 1000 feet, that part of the lake-district north of the main watershedding line would communicate with that south of it by only one channel, which we may call the "Straits of Dunmail Raise." The height of this pass (Dunmail Raise) is 783 feet. All the other valleys of the area under consideration would be closed fiords, except the great east and west vale of Keswick.

At the 1250 feet submergence the straits of Dunmail Raise would still be the only *through* passage (fig. 2). But instead of each of the other valleys—except the vale of Keswick—being simple fiords, the Buttermere and Borrowdale would communicate by the Honister Straits, and the range of mountains on the east side of the Buttermere and Lorton Valley be split up into three large islands parted from one another by Newlands Straits and Whinlatter Straits.

At 1500 feet (fig. 3), Dunmail Raise would still be the only *through* strait; but now the Ennerdale fiord would communicate with the Buttermere and Borrowdale waters by the straits of Scarf Gap, and Skiddaw and Blencathra be separated by a strait of some width.

Fig. 1.—*Contour-map, showing the form of the land when the submergence had reached* 1000 feet. Scale 3 miles to $\frac{7}{12}$ inch.

Fig. 2.—*Contour-map, showing the form of the land at* 1250 feet.



At 1750 feet (fig. 4) the breaking up of the land would be complete. Several communications between the northern and southern parts of the lake-district would exist, and the Helvellyn range form the only tract of land at all continuous.

Fig. 3.—*Contour-map, showing the form of the land at* 1500 feet.

Fig. 4.—*Contour-map, showing the form of the land at* 1750 feet.

At 2000 feet (fig. 5) the whole lake-district would consist merely of scattered islands, of which those of Helvellyn and Scafell would be the most considerable; while at 2500 feet the proportion of land would be very small indeed.

Fig. 5.—*Contour-map, showing the form of the land at* 2000 feet.

VII. Axioms to be borne in mind in drawing Conclusions.

In drawing conclusions from all that has now been brought forward, I would wish to bear in mind the following axioms:—

1. That a great series of glacial scratches, all pointing in the same direction, evidences the onward movement of a sheet of land-ice, and is not likely to be due to drifting and floating ice.

2. That the height to which such *uniform* scratches extend upon the summits of mountains is an index of the amount of hill-area covered by the ice-sheet; and that the height to which they extend upon the sides of valleys is an index of the least thickness of the ice in such valleys.

3. That the onward motion in one constant direction of a great thickness of land-ice would tend to push and carry forward portions of the underlying and surrounding rocks in the same direction.

4. That floating ice might bear boulders in directions in which land-ice could not have transported them.

5. This being the case, it is evident that boulders from very different regions may be commingled, one set being pushed forward by land-ice from one direction, and another set being floated, at a different time, from quite another direction.

6. Since changes in geography affect ocean-currents, boulders may be floated at one stage of submergence in one direction, and at another stage of submergence in some other direction, thus, again, causing boulders from distinct regions to be commingled at the same spot.

7. That where a body of land-ice is confined within the narrowest limits, there, if anywhere, will it be most likely to be pushed over the enclosing walls on one side or the other.

8. That, in such a case, the *push* will be given from that direction

whence the greatest body of ice comes; and consequently the enclosing wall most readily surmounted will be that opposite to this direction.

VIII. Conclusions.

At the commencement of the cold period the glaciers formed small terminal moraines high up the valleys. As the cold increased, the glaciers enlarged, the old moraine matter was partly pushed onwards, partly overridden; at last on the cold attaining its maximum, most of the glaciers were united to form a more or less continuous ice-sheet.

1. *Ice-sheet or confluent-glacier Period.*—This is distinguished by the ice not being *strictly* confined to the valley system in which it originated, but occasionally being thrust by lateral pressure and pressure from behind over watersheds. During this period the ice from the upper reaches of Borrowdale was alone sufficient to fill the valley, and it passed over Castle Crag (900 feet) and exerted much abrading force on squeezing through this the narrowest part of the vale. This great Borrowdale glacier was also continuous with another great ice-sheet which swept in a N.N.W. direction across the Watendlath and Grange Fells, being, it would seem, partly reinforced by ice pressed over from the Thirlmere valley across the watershed by Blea Tarn.

The ice at the head of the present Derwent Water was thus in such quantity that the western part of the Borrowdale glacier was caused to overlap the ridge of Cat Bells, and partly occupy the Vale of Newlands, just as part of the modern Aletsch glacier overlaps a bounding wall and occupies a side valley. Great ice-sheets also came down the Newlands valley and its tributaries to swell the size of the Borrowdale glacier.

The ice in the Thirlmere valley was of such a thickness and so pressed against the western side by the great supplies off the long Helvellyn range, that, as already noticed, it partly escaped across the western watershed south of Armboth Fell, and also took, in great part, a north-westerly course on reaching the lower end of the valley. It would seem, indeed, that the sheets of ice from the Thirlmere and Borrowdale valleys were united in the low ground north of Castlerigg Fell, and that the whole of Keswick Vale from Threlkeld to Bassenthwaite was filled with ice, which abutted against the flanks of Skiddaw, and perhaps of Blencathra, just as the old Rhone glacier abutted against the flanks of the Jura. Like the great old Swiss ice-sheet also, this probably sought an exit from the vale in two directions, one to the east, beneath the slopes of Blencathra, and the other and main one to the west, towards the low ground below the present Bassenthwaite Lake. This mass of ice in Keswick Vale may also have been increased by sheets from the southern slopes of Skiddaw, Blencathra, and the intervening valley of the Glenderaterra.

The ice, sufficient in quantity to block up Keswick Vale where widest, had, on the west, to be squeezed through the narrow neck, not more than a mile wide, between Dodd and Barf. The result of this seems to have been that much of it was forced over the fells between Whinlatter and Wythop, the higher tops being alone unenveloped.

The Buttermere glacier, though large, probably could not compare with that of Borrowdale, fed by larger areas of fell. Its source was derived from Fleetwith behind Honister Crag, some of the ice passing on the north and some on the south of the Crag. Lower down it was added to by glaciers shed from the mountains and combes on either side, especially by those of the High-Stile and Red-Pike range.

About Scale Force the western side of the glacier would seem to have divided on either side of Mellbreak, part turning due west and joining the ice flowing from Great Borne and Gale Fell, down the valleys on the western side of Mellbreak. At the northern end of Mellbreak the glacier-sheet would seem to have again divided, the main mass continuing down the vale of Lorton, but a branch finding an outlet to the west by way of Loweswater. Very possibly, however, at the time of greatest ice-extension, the ice may more or less have enveloped and passed over the oblong tract of highish ground (from 1000 feet to 1300 feet) between Loweswater and Lorton.

The long straight Ennerdale valley was also at this period in great part filled with ice, the higher feeding-grounds being the north and western slopes of Kirk Fell, Great Gable, and Green Gable, while the many combes along the Pillar range on the south side of the valley each contributed its glacier to the main stream. The ice seems to have passed over Latter Barrow at the east end of Ennerdale Lake, and to have exerted much pressure on emerging from the valley between Crag Fell on the south and Great Borne on the north.

The overriding of parting ridges by the confluent-glacier ice is also very evident on the western side of the Ullswater valley.

2. *Mild Interglacial Period.*—The existence of at least one mild interglacial period is, I think, shown by the following considerations*.

a. *Sand and Gravel mounds.*—The mounds of stratified sand and gravel already mentioned occur up to 800 feet at least without containing large boulders or angular blocks ; above this height, up to 1050 feet, similar sand and gravel mounds contain boulders. In both cases, however, boulders, often of large size, are found *upon* the mounds.

The mounds were formed by the meeting of tides and currents during a submergence of the land, and they are consequently formed for the most part at the ends of valleys. The question, however, is, whether a mild period had come on before the submergence began, or whether the country went down beneath the sea ice-clad, and the climate was changed to a mild one before its complete re-elevation. Now the sand and gravel mounds without boulders imply an absence of floating ice ; and the fact that boulders are found *on* but not within

* I cannot find any facts in *this* district to suggest a cutting up of the *Ice-sheet Period* by several mild seasons.

the mounds below a certain height, points to a cold period *succeeding* one less cold. Moreover the mounds between 800 and 1000 feet, which contain boulders, show the presence of floating ice at a time when the land was thus far submerged; if a mild period *succeeded* that time and continued until the non-boulder-bearing mounds were formed at various heights between 800 and 250 feet, it is evident that the scattered boulders *upon* the mounds could not have been deposited by floating ice. Hence they must either have been left by a new set of large glaciers, produced after the emergence of the land, or the above theory falls to the ground. That glaciers did exist *after* the emergence of the land is sufficiently evident; but that they were of such size as to spread out into much of the low ground there is no evidence, even if it were likely that great glaciers could ride over mounds of loose sand and leave boulders perched upon them. Therefore the supposition that the mild period occurred during the *re-elevation* of the land is false.

But another supposition is possible. The mild period may have come on before the subsidence even commenced, and have continued until the land had sunk some 800 feet beneath the sea. During the gradual sinking sand and gravel bars might be produced at various heights, when there was no floating ice to transport large boulders. But if cold then began to return, the mounds above 800 feet might contain ice-transported blocks, and boulders would be dropped *upon* the earlier-formed mounds. And this, I think, is what really did happen.

It may, however, be that the boulder-containing mounds above 800 feet were formed *not* during the subsidence, but during the re-elevation, even although they seem from their position to be one with the non-boulder-bearing mounds at slightly lower elevations. For when the land stood at about the same height during subsidence and during elevation, there might be a like tendency to the formation of sand bars at nearly the same spots, only that in the one case the mounds would not contain boulders—during a mild period—and in the other case they would—during the succeeding cold period. Hence, while the *occurrence* of mounds without contained boulders, but having boulders upon them, points to a submergence with a mild period, at all events until the land had sunk some 800 feet, it is merely the *absence* of such mounds at a greater elevation than 800 feet that would suggest the cold period *then* coming on. Mr. James Geikie, in his admirable memoir on "Changes of Climate during the Glacial Period," after pointing out that the mild period had come on before the subsidence commenced, expresses his belief that the cold only began to return when the submergence was approaching its limits. If future investigations in the lake-district should lead to the discovery of mounds without contained boulders at a higher elevation than 800 or 900 feet, my observations would almost completely support his conclusions. I may add that I purposely refrained from consulting Mr. Geikie's paper until I could form my own conclusions from such evidence as these facts afforded, and was then most pleased to find that our inferences were so nearly alike.

So that the facts in this district point to:—1st, the gradual appearance, the continuance, and the disappearance of a great ice-sheet more or less enveloping the district; 2nd, a mild period and gradual subsidence to at least 800 feet; 3rd, a cold period with a continued subsidence and subsequent re-elevation.

b. *Amount of Submergence.*—Finally, the question arises, to what extent was this submergence?

There are some facts which have been brought forward under the head of boulders and their positions, that are more easily explained by the action of floating ice than of land-ice. If we grant that the stratified sand and gravel up to 1000 feet is sufficient evidence of submergence to that point (though at present no marine shells have been detected in these deposits), we may perhaps also conclude that the occurrence of the subangular drift-gravel up to 1500 feet also points to a submergence to that depth. Boulder-evidence strengthens this conviction; thus the boulders borne on to Broom Fell from a couple of miles to the north, at a height of 1200 feet, point clearly to floating ice, as the direction is not that of any possible land-ice stream. On the southern side of Kirk Fell (adjoining Broom Fell), a boulder of the Buttermere syenite rests at nearly 1200 feet; its presence there is most readily explained by floating ice; for it could not have been left by the Buttermere-and-Lorton-Valley glacier when at its largest, because other great sheets of ice, shed from the Grisedale Pike and Whiteside mountains, would have staved off the Buttermere ice more to the west, and prevented its *running up* among the mountains on the east side of the valley.

The syenite boulders upon the top of Starling Dodd, at a height of 2084 feet, are suggestive of submergence even to that amount; for it is difficult to see how they could have got there by the action of land-ice, since the only syenite at an equal height is near the summit of Red Pike (19), one mile due east, upon the same water-shedding line passing over Starling Dodd, which line is depressed between the two summits to 1880 feet. I am therefore inclined to think that these boulders must have been floated either from Red Pike westwards, or northwards from the high syenite mountains upon the south side of Ennerdale and west of Haycock (25). The position of ash and trap boulders on syenite, along Lingcomb Edge (the western boundary of the combe below Red Pike), up to a height of 1750 feet, is also more readily explained by flotation from east to west than by land-ice, when the relative lie of the various rocks is taken into consideration. Many other instances might be given which seem to support the idea of submergence to *over* 1500 feet; and although future evidence may modify opinion upon the subject, I cannot but think it highly probable that the submergence even reached to the height of 2000 feet or rather more.

During this submergence the vast quantity of moraine matter left in all the low grounds by the preexisting ice-sheet, was much remodelled and converted in great part into the subangular drift-gravel already described.

c. *Direction of Marine Currents.*—It becomes an interesting question to consider in what directions currents may have flowed to transport boulders. We have already seen that not until the submergence exceeded 1500 feet could there have been any through passage between the southern and northern parts of the present lake-district, except by the straits of Dunmail Raise. That a current passed through these straits *from north to south* seems improbable, since no boulders of the rocks of Skiddaw and Blencathra are found anywhere along the St. John's or Thirlmere valleys. If, however, a current at one time ran through these straits *from south to north*, we should not expect to find boulders of the *Upper* Silurians of the southern part of the lake-district transported north of Dunmail Raise, since there are scarcely any points due south of the straits where the Upper Silurians attain the elevation of 1000 feet. Again, it is somewhat significant that no boulders of the Volcanic series have been detected *up* the valley of the Glenderaterra, between Skiddaw and Blencathra; hence we can scarcely suppose that any current ran through that gap from *south* to north, though many boulders of granite and hornblende slate have travelled *southwards*, and then *principally westwards* towards Bassenthwaite.

Of course it is very difficult to say how much of this transport of boulders has been due to floating and how much to glacier ice; and it is very probable that the directions of transport in the two cases were to a great degree the same. Thus I should be inclined to conclude that, when the submergence had reached 1500 feet, there may have been a current setting through the straits of Dunmail Raise *from south to north*, turning eastward on reaching the end of St. John's Vale, though perhaps sending off a small branch westward as well—also that a current may have set through the straits between Skiddaw and Blencathra *from north to south*, turning for the most part westward on gaining the wide channel of Keswick Vale. It is quite possible, however, that before the submergence had reached 1500 feet, and before the strait had been opened through between Skiddaw and Blencathra, a main current passed through what is now Keswick Vale from west to east, skirting also the whole district on the west, across the end of the Vale of Lorton, and dispersing the greenstone boulders from Sale Fell southwards to Broom Fell. I fully trust that more extended observations to the north and east of the area now described may either confirm or prove the incorrectness of such surmises as to the directions of these old currents.

3. *Period of Local Glaciers and Re-elevation.*—The non-occurrence of true moraines over any part of the area occupied by the drift gravel is, I think, sufficient evidence that there was no return of the great ice-sheet or even of *very* considerable glaciers after the land had been re-elevated. All the main upland valleys, however, had their glaciers during this later cold period; and the fresh-looking moraines now to be seen in them are the last relics of our Glacial Period.

In this paper I have been dealing solely with that part of the district north of the great east and west watershed; I may here add that, so far as I have myself examined the country south of that line, the evidence seems similar to that already brought forward. Wastdale, Langdale, and Easdale all bear evidence of a great more or less confluent ice-sheet moving southwards from the main watershed, the ice in Langdale and Easdale bearing south-eastwards, that in Wastdale south-westwards, while the many perfect upland moraines belong to the last and smaller set of glaciers. To the confluent-glacier or ice-sheet period are to be assigned also, most probably, moraines found on high passes—as, for instance, in the Stake Pass, between Langstrath and Langdale,—though these may in some cases have been modified by the action of currents during the period of submergence.

IX. Summary.

1. There is no evidence that a great ice-cap from the north ever completely swept over the district, the ice originating in it being probably sufficient to stave off any such northern flow.

2. The ice-scratches, tending *mainly* along the principal valleys, but sometimes crossing watersheds and over high ground, point to a great confluent glacier-sheet, at one time almost completely enveloping a great part of the district.

3. The movement of this ice-sheet was determined, to the north and to the south, by the principal watershed of the lake-district running through its centre, approximately east and west.

4. In that half of the district under consideration, the ice, on its increase from small glaciers to a large ice-sheet, moved onwards a great quantity of rocky material from south to north; this was done partly by the forward pushing of the first-formed moraines, and partly by the ice overriding the same and dragging on the fragments beneath it.

5. This particular district gives no evidence of one or more mild periods occurring in the great epoch of *primary* glaciation; but then the area of the district is but small.

6. The climate, however, had probably become moderate, and the glaciers almost or quite disappeared, before the commencement of the great submergence of the land.

7. During the earlier part of this submergence mounds of sand and gravel were formed in certain positions by tides and currents; and these contain no large boulders. All the old glacial material was also remodelled in great measure and partly rounded.

8. When the land had sunk some 800 or 900 feet the cold began to return, and floating ice transported boulders, which were enclosed in sand and gravel mounds formed *after* that time, and dropped *upon* the older non-boulder-bearing mounds.

9. Not until the submergence had reached over 1500 feet was there any *direct* communication between the northern and southern halves of the lake-district, *except* by the straits of Dunmail Raise.

10. Under such conditions a current very probably ran through these straits from south to north, turning mainly to the east on reaching Keswick Vale, though probably sending a branch off to the west. Hence boulders may have been transported by floating ice in

some of the same directions as they had previously been carried by glacier-ice.

11. A current also probably swept from north to south along the north-western outskirts of the district in question, when the land stood at about the 1200 contour, either during the submergence, or during the re-elevation, or possibly during both. The skirts of this current carried the ice-borne boulders from Sale Fell southwards on to Broom Fell.

12. The situation of stranded boulders in many parts of the district makes it probable that the submergence reached to rather more than 2000 feet.

13. On the re-elevation of the district there was a second land-glaciation, all the higher valleys being more or less filled with ice, which cleared away any marine drift deposited in them; but it would seem that the ice attained nothing like its former extension, as no moraines are found upon the subangular drift-gravel of the wider valleys.

EXPLANATION OF PLATE XV.

Map showing the direction and height of the ice-scratches, together with old lake-beds in the northern part of the lake-district.

Discussion.

Mr. Campbell stated that he had not visited the district. He thanked the author for his able statement of facts. He agreed with his reasoning, which proved the former existence of a "local ice-system" equal to Irish, Welsh, and Scotch systems, in the districts which he had examined and described. With reference to the position of certain boulders at high levels and their transport, it seemed to be an open question, worth the author's consideration on the ground, whether these stones had floated over deep water on ice-rafts, or had been moved by the flowing of deep ice when these hollows were full to the level indicated, and when British local systems were united. In similar cases he had been led to the latter explanation of facts which he had observed in Ireland and elsewhere.

Prof. Ramsay complimented the author on the careful manner in which he had worked out his subject, He thought, however, that many of the principal features described had already been sketched out, though no doubt much knowledge had been added as to details. As to the question of general glaciation, he thought it probable that much of the northern part of Europe had at one time been coated with ice, and to such an extent that it occupied the greater part of the bed of the shallow seas. But even if there were this great ice-sheet, and the general direction of its flow was from north to south, yet there might, in the body of the ice, be upper and undercurrents, going to a certain extent in opposite directions, and mainly guided by the surface configuration of the ground beneath. He thought that some trace of this might be found in existing hilly regions, and that, especially in deep valleys, the upper portion of the ice must, of necessity, have had a tendency to pass over that which occupied the bottom of the valley. With regard to oscillation of temperature and of level, he agreed with the author, and was glad to find that his views as to a submergence of about 2000 feet so nearly corresponded with his own. So long as marine remains were found from stage to stage in a certain class of deposits, the probability of similar deposits at a higher level being also marine, was so great that it almost amounted to certainty. He considered that the importance of the latter part of the Glacial period was liable to be underrated; but it was well evinced by the depth (in some cases amounting to 1400 feet) to which some valleys, such as those of North Wales, appeared to have been filled with ice after the re-emergence of the land.

Mr. Ward, in reply, stated that, though he had found striations to a height of from 2000 to 2500 feet, he had not found them on the highest summits of the mountains, where, on the hypothesis of a general ice-sheet, they ought to have occurred. He was therefore not at present prepared to accept the ice-cap theory. In illustration of Prof. Ramsay's view as to the late glacial deposits, he instanced some of the moraines at a high level in the Lake-district, which belonged to the period when the land was still submerged to a depth of 1300 feet or so, and when the cold climate was again supervening.

1 Ullscart, 2370. 2. Glara 18. 7. Steel Fell, 1811. 8. Blencathra, 2847. 9 Skiddaw, 3054. 10. Barf, 1536.
11. Robinson 2417. 12. Hin 317. 17. High Crag 2443. 18. High Stile, 2643. 19. Red Pike, 2479. 20. Mellbreak 1676.
21. Carling Knott 1781. 2 Dodd, 2756. 27. Dollywaggon Pike, 2810. 28. Raise, 2889. 29. Lords Seat, 1811.
30. Broom Fell, 1670. 31. ling Dodd, 2084. 37 Gavel Pike, 2577. 38 Arnstone Crag, 1423. 39 Fairfield, 2862.

Minter Bros lith.

low 500 ft. Filled up Lakes.
ks.