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From the writer

Glacial Period

The GLACIAL PHENOMENA of the EDEN VALLEY and the WESTERN PART of the YORKSHIRE-DALE DISTRICT. By J. G. GOODCHILD, Esq., of the Geological Survey of England and Wales.

[PLATE II.]

IN the following paper it is proposed to take up the investigation of the North-Anglian glacial phenomena in the district north of that treated of by Mr. Tiddeman in his paper on the Evidence for the Ice Sheet in North Lancashire, &c.*, to carry on the observations northward among the Carboniferous dales on the eastern side of the Lake district, and to endeavour as far as possible to throw some light upon the glacial phenomena of the Eden valley.

Most of the facts were obtained in the course of the Geological Survey of the district by Professor Hughes and the writer, and are given here with the permission of the Director-General. Those relating to much of the Eden valley, properly so called, were collected by the writer in his holiday rambles in 1873-4, and are introduced here to supplement the more detailed observations that have been made on the part of the district hitherto mapped by the Survey.

The Ice Sheet, and Boulder-transportal.

The physical features of the district need not be described in detail, as the accompanying map (Plate II.) will give a better idea of them than could be gathered from many pages of description. There are, however, a few points to which it is desirable that attention should be called, in order that the following remarks may be the better understood.

Generally speaking, we may say that the greater part of the high ground of which Ingleborough, Whernside, and Gragreth form parts lies to the E.S.E. of a line joining Kirkby Lonsdale and a point a little to the north of Kirkby Stephen. The highest fells in this area range from about 2200 feet to 2400 feet above the sea. Most of the principal elevations lie within a few miles of the N.N.E. line just mentioned: to the E.S.E. of this area of highest ground the uplands gradually decline to the level of the plain of York. To the south it is well defined by the line of the Craven faults; and it will be convenient to take the strip of comparatively low ground known as Stainmoor as its northern boundary. Within these boundaries the uplands are much cut into by dales, of which the two principal are Wensleydale and Swaledale. The whole of this area is generally spoken of as the Dale district; it will therefore be convenient to use that name when referring to it further on.

Lying to the north-west of the Dale district is another great up-

* Quart. Journ. Geol. Soc. vol. xxviii. p. 471 (1872).

land tract, the summits of which range up to nearly 2900 feet. As in the case of the Dale district, the plane of the fell-tops of this area gradually slopes to the east, and passes into the low country of the Durham Coal-measures and Magnesian Limestone. To the south-west this area is limited by the north-westerly Pennine Faults, which range, roughly speaking, from Brough, in the north-east corner of Westmoreland, to Brampton, not far to the north-east of Carlisle. Between the lines of disturbance and the tops of the highest fells the ground rises very rapidly, forming a bold escarpment that in one place rises more than 2000 feet above the adjoining low ground of the Eden valley. Cross Fell, the highest point, is 2892 feet above the sea; and as this Fell necessarily forms a prominent object many miles around, it will be well to speak of the escarpment that it forms part of as the Cross-Fell escarpment, and to call the great tract of moory uplands to the north-east and south-east of it the Cross-Fell district.

A tract of low ground, having but few points in it above 1000 feet, and the greater part below 500 feet above the sea, extends from the foot of the Cross-Fell escarpment to the north-eastern limit of the Lake district. It is more of the nature of a plain gently inclined towards the Pennine escarpment than of a valley, properly so called; but from the circumstance that the river Eden flows through it, it has come to be generally known as the Eden valley.

Westward from the Dale district lies the flattened dome-shaped mass of the Lake country, which is too well known to need any description here. Part of this area is prolonged as a kind of geographical outlier to the east of the depression that the river Lune flows in up to the line of the north-easterly faults; and the generally easterly line of watershedding of most of the Lake-district streams is extended through this all but detached area of Silurian rocks, across the Great Faults, to Wilbert Fell, and thence between the headwaters of the rivers Lune and Eden, crossing the principal watershedding line of Northern England, to the line of high ground between Wensleydale and Swaledale.

It will be well here to make a few remarks upon the lithological character of the rocks within the area now being treated of, so that the evidence for the direction of flow of the boulder-transporting agent may be rendered clearer.

Beginning south of the northernmost of the Craven faults, between Ingleton and Leck, we find an outlier of Permian rocks lying upon the Carboniferous beds on the downthrown side of the fault. Amongst these Permians a breccia of a marked lithological character occurs; and a similar rock is nowhere to be found anywhere in place to the north of the Craven fault nearer than the Eden valley. A few miles to the east of this Permian outlier the streams that flow southward from the uplands about Ingleborough, Whernside, and Penyghent have cut down through the Carboniferous rocks into the older Silurians that form the floor whereon the newer beds rest. The Silurian rocks differ greatly in lithological character from the Carboniferous beds, so that fragments of the two

kinds of rock are easily distinguishable in any section of drift where they may happen to be intermingled.

The Silurian inliers extend only about two or, at the most, three miles into the Dale district. Northward from that the Dale rocks are wholly Carboniferous, and generally speaking may be said to consist of:—a lower series of limestones, sandstones, and shales, the last predominating over a large part of the area that this paper refers to; and an upper series, which commonly occupies the higher ground, and consists of alternations of grits, sandstones, and shales. Occasional thin limestones are found in part of the area, but they are usually distinguishable in lithological character from the thicker limestones of the lower group. Except that in one part of the Dale district there are a few veins of silicified limestone of a character sufficiently well marked to allow them to be used as tests of the way that the drift moved, but few rocks are found of such a character that one may identify fragments of them amongst the drift derived from other rocks in the neighbourhood. Fortunately, however, the highest thick limestone of the Yoredale rocks is so much unlike any of the beds above it that it may be safely used to determine this point.

Along the western border of the Dale district the case is far otherwise. The long line of faults joining the Craven- and Cross-Fell branches of the Pennine faults may be said, for more than half its length, to mark off the Silurian area from that occupied by the Carboniferous rocks.

Northward from Leck to near Sedbergh the Carboniferous rocks abut directly against the Silurians; but beyond this, strips and patches of the red conglomerates of the Upper Old Red, and occasional strips of the peculiar apple-green quartz conglomerates of the Lower Limestone Shale, appear at intervals among the faults to a point about two miles south of Rawtha bridge. Both of these rocks are quite unlike either the Silurian or the Carboniferous rocks that they are faulted amongst; they may therefore in most cases be relied upon as tests.

Just to the north of the inliers of Upper Old Red and Lower Limestone Shale alluded to, bosses of diorite come in the Lower Silurian rocks near the faults. Portions of it are of a well-marked character, and can easily be identified amongst drift stones from any of the rocks around.

Passing onwards to the Eden valley, we come upon the peculiar deposit that is locally known as "Brockram." This is a breccia, or a series of breccias, of fragments of Carboniferous rocks, mostly of limestone, in a red sandy matrix, forming a rock of great durability, that comes to the surface as a strip varying in width from 1 to 3 miles. In no instance known does the Brockram in the Eden valley lie higher than 700 feet above the sea; most of it lies between the 500- and 600-foot contours. Its principal areas of outcrop lie to the south of Kirkby Stephen, and near Appleby, to the north of which the rock is generally less compact and durable, and in large masses is distinguishable from that which occurs in the typical areas. A few exposures of Brockram occur at intervals in the low ground

skirting the foot of Stainmoor round to Brough; but, as before stated, none of these lies higher than about 650 feet above the sea.

Along the Cross-Fell escarpment there are only two rocks of any value for our present purpose. One of these is the Whin Sill, a bed of basalt that occurs among the Carboniferous rocks in the escarpment, but does not extend further than about five or six miles to the north-west of Brough. The other rock alluded to is the conglomerate that is elsewhere described as part of the Roman-Fell series*. Neither the Whin Sill nor the conglomerate affords a very satisfactory test. Much of the Whin so closely resembles some of the igneous rocks associated with the Silurians of the Lake district that it is often difficult to distinguish between them in cases where fragments of both have got mixed together in the drift. Parts of the Whin, however, may be recognized by those who have seen much of it in place. The finer parts of the conglomerate are so much like the Millstone Grit that they cannot always be relied upon as a test; but the coarser parts, especially where accompanied by the usual matrix, are of more value, and may be traced in the drift a long way from the parent rock. Bearing in mind the occasional uncertainty of any identification of drift fragments of the rocks just mentioned, they have only been made use of for the purpose of proving which way the drift has moved in cases where the fragments are not to be mistaken.

Turning now to the Silurian areas south of the Eden valley, we do not find any very marked types of lithological character in the Howgill Fells; or, if they exist, the writer is not well enough acquainted with them to be able to trace them far from the parent masses. The same remark also applies to the Silurian areas between the river Lune and the point where the oft-described Shap Granite comes to light. Now that this beautiful granite is being so extensively used for ornamental purposes it is needless to give any description of it here, as all geologists who have taken an interest in the glacial phenomena of Northern England must have acquired more or less familiarity with its appearance long ago.

Between Shap Fells and Ullswater the rocks belong to the so-called "green-slate-and-porphry" series, and have not in any instance been made use of for the purpose that this part of the paper treats of, because of the writer's imperfect acquaintance with them.

Westward from Ullswater a great variety of igneous rocks of well-marked lithological characters come among the Silurians on the north side of the Lake-district watershed. Most of these have been referred to by Mr. Ward, in his paper on the Glaciation of the Northern Part of the Lake-district †. The writer's acquaintance with some of these rocks is partly due to Mr. Ward's identification of fragments from the drift, and partly to the information gained by several days' hammering over some of them in place, especially those that occur in the Caldbeck Fells.

The igneous rocks alluded to, that have mostly been relied upon

* *Quart. Journ. Geol. Soc.* vol. xxx. p. 398 (1874).

† *Ibid.* vol. xxix. p. 422 (1873).

in making out which way the drifts of the Eden valley have been moved, are the syenites of St. John's Vale (near Keswick), of Carrock Fell, and of Buttermere, the porphyries of Berrier Nittles and of High Pike in the Caldbeck Fells, the granites of the Calda and Brandy Gill, and the peculiar porphyritic dyke of Arnboth Fell and the Helvellyn. Other Lake-country rocks that the writer has not had opportunity of examining in place are not taken into account here, especially as those just named do well enough for the purpose in view.

Turning next to the subject of the glacial markings and the course taken by the ice, it will be well to begin at that part of the Dale district that lies immediately to the north of the Craven fault. Mr. Tiddeman has already alluded to part of this in his paper before mentioned; it is referred to again in this place because a little additional evidence has been obtained since his paper was written. Most of this part of the Dale district was mapped by Professor Hughes, who has allowed the writer to make the fullest use of any information relating to the glacial phenomena of the district.

Mr. Tiddeman has demonstrated that the drift-transportal and the rock-grooving of the country a long way to the south of the Craven faults, on the west side of the Pennine watershed, were effected by a thick sheet of land-ice, which must have come from the country somewhere to the north of the Craven fault; and the object of this part of the present communication is to point out the line of departure whence this branch of the great ice-sheet started.

No fragments of the Brockram, which is mentioned above as occurring to the south of the Craven fault, between Leck and Ingleton, have ever been found to the north of its present area, although pieces of it are found in the drifts that occur to the south-east of it, and probably also in those that lie to the south.

The Silurian areas of Chapel-le-Dale, Crummaek, and Horton-in-Ribblesdale have yielded no boulders that have travelled to the north. The rocks themselves are quite unlike the overlying Carboniferous beds; if, therefore, fragments of them really occurred in the drifts to the north, it would be an easy matter to trace them to their origin. It may be objected that the later glaciation may have ploughed out the older drift, and that, as the glaciers would necessarily follow the ordinary lines of drainage of the country, they would replace the Silurian drift by other drift brought from the Carboniferous uplands to the north. This will be referred to further on, when the drifts themselves are being treated of.

The scratches about Ingleborough have already been described in Mr. Tiddeman's paper*; they are reproduced on the accompanying map in order that their relations to the scratches that have been found in the country to the north may be easily seen.

Between Gragreth and Wherside two scratches ranging about N.N.E. have been found on the very summit of the pass; and one or two others having the same direction have been met with at lower elevations on the south side; but none of these affords any satisfactory evidence as to which side of that line of watershed the ice came from.

* *Loc. cit.* p. 476.

Turning now to the southern end of the line marked A on the map, and which runs very nearly along the line of contact of the Silurian and Carboniferous rocks, we get evidence of a much more satisfactory character. To the east of this line we find that the drift is wholly made up of Carboniferous stones, while fragments of the adjacent Silurians are very rare, if not entirely absent; but on some parts of the west side of the line, Carboniferous drift extends some distance over the wonderfully *moutonnés* Silurians, while isolated boulders of Carboniferous origin range almost up to the summit at the north end of Barbon Fell. Further to the north the Middleton Fells afford evidence of the same kind, the Carboniferous drift from Dent having been thrust over part of the Silurian area, while to the east of the line A Silurian stones are not yet known to occur at all.

Any geologist who looks at the eastern corner of the Middleton Fells from Rysell, or from Helms Knot, cannot fail to notice the remarkable instances of glaciation on a large scale which these fells present. Professor Hughes long ago pointed this out in a paper read before the Leeds Philosophical Society. In lithological character these Silurians consist of alternations of hard and softer beds, tending under ordinary circumstances to weather into terraces that follow the lines of gentle curvature of the beds. When seen from a little distance, especially if the sun is not too high, the terraces are seen to be traversed by a great many roughly parallel ruts, which cross the strike of the beds at small angles. For short distances the glacial grooves coincide with the strike of the softer beds, and then mount the next bed above, and so on to the summit, beyond which the ice seems to have held its course nearly along the strike of the beds down to the Lune valley. Professor Hughes has pointed out that the ice-sheet must have split against the east corner of the Middleton Fells near Coum Scar, so that one branch of it flowed nearly along the course of Barbon Beck.

On the south side of Dent no satisfactory evidence can be got from the scratches; but on the eastern end of Rysell others occur on the top of the ridge with a direction about W. 30° S. It will be seen by the map that to the east of this several other striæ, having nearly the same direction, occur at various levels up to the 2000-foot contour, and that these high-level scratches seem to be in no way affected in their general direction by the form of the adjoining ground. In the cases just referred to there is no direct evidence to show which way the ice moved, although it is tolerably clear that the ice that overrode the Middleton Fells did not start from either Rysell or Widdale Fell, as the scratches do not radiate from the highest ground there, but point as if they went clean over it.

The writer has long suspected that part of the ice that filled the hollows where Widdale Beck, Snaizholme Beck, and Duerly Beck, at the head of Wensleydale, now flow, moved up those dales instead of down them, as would have been thought likely. In the two first-named dales the drift has not helped to make this point clear; but on searching on the high ground to the east of Dod Fell, at the head of

Duerly Beck, the writer found unmistakable drift, containing glaciated fragments of the Yoredale limestones, high up on the Millstone Grit of the watershed. Amongst the drift there were not only stones from the highest of the Yoredale limestones, easily recognizable by its encrinital character, but also fragments of some of the dark grey limestones that occur at much lower elevations. The value of this piece of evidence is great, as demonstrating that part of the ice that environed Ingleborough in so remarkable a manner came from still further north than the line of high ground between the Yore and Wharfe.

On Wetherfell, about two miles to the N.N.E. of the place where the up-carried drift was found on Dod Fell, Mr. Dakyns, of the Geological Survey, found scratches ranging south-easterly at an elevation of nearly 1800 feet above the sea. These afford another proof that the great ice-sheet flowed across the head of Wensleydale, and that its line of departure must therefore be still further to the north. The remaining scratches on the south side of the line of diamond-shaped dots on the map do not help to prove much; those in the low ground conform, as they usually do, to the direction of the part of the valley wherein they occur. The scratches on Sails, again, do not help much to show which way the ice moved; and the same may be said of those on the east side of Baugh Fell. There seems, however, to have been a line of ice-shedding nearly coincident with that between the head of Garsdale and the part of Wensleydale known as Lunds: to the north-east of this line the striae trend to the south-east; and on the Garsdale side the lower striae conform more or less to the direction taken by the river Clough. On the top of Baugh Fell several well-striated rock surfaces occur at different elevations between the 2100- and 2200-foot contours; their general direction is west-south-westerly, with a few pointing nearly due west. Scratched-stone drift occurs on the north side of the Fell up to 2100 feet above the sea. In this case the glaciation appears to have been very slight, as, in one or two instances, not represented by arrows upon the map, the ice seems to have done little else than plane off the crests of the ridges between the ripple-markings on the surface of some of the blocks, leaving the hollows in nearly their natural state. Other instances seem to show that the glacial action has only shorn off the upper parts of the quartz pebbles that weather out on some parts of the rock, leaving flattened surfaces that show very minute striae preserving a generally parallel direction over large slabs of rock. These, however, may be partly due to the easy separation of the slabs of rock along the bedding-planes, in consequence of the small thickness of preglacially weathered rock that the brief stay of the ice at these high elevations enabled it to remove. The scratches represented upon the map are very well marked, and may be found easily enough by any one who cares to look for them.

Passing now to the drifts about Rawtha bridge, and those that occur just to the north of the Bluecaster diorite, we find unmistakable evidence of the northward transportal of the drift, and

therefore that the line of ice-shedding must have been crossed. The drifts just mentioned contain stones from the Upper Old Red conglomerates, others from the Lower Limestone shale; and along with these well-glaciated fragments of the Bluecaster diorite come in the drifts to the N.N.E. Some of these drift-stones may be traced nearly three miles to the N.N.E. of the nearest rock of the kind in place.

On Swarth Fell east-north-easterly striæ occur at elevations between 1950 and 2200 feet above the sea, on the same bed of rock as that which has preserved the Baugh-Fell scratches. In one instance they are crossed by a set ranging nearly S.E. Some of the scratches are distinct enough; but the remainder are very slight, like those mentioned as occurring on Baugh Fell. None of these striæ prove which way the ice flowed.

On the watershed between Mallerstang and Lunds north-north-easterly scratches have been lately bared in the cuttings along the Settle and Carlisle Railway; and at Riggs, about a mile to the N.N.E. from the spot where these striæ occur, some remarkable veins of silicified limestone have furnished boulders which have travelled in a northerly direction. A reference to the map will show that it is probable that the line of ice-shedding here nearly or quite coincided with the present line of watershed between the Eden and the Yore.

A few other valley-striæ occur in Mallerstang, but they do not call for any particular remark; but on the bold line of Millstone-grit crags, known as Mallerstang Edge, a bed of gannister, on the same geological horizon as that which bears the glacial markings on Baugh Fell and Swarth Fell, shows two sets of striæ ranging north-north-easterly, at elevations about 2100 to 2150 feet above the sea. In these cases, again, there is clear evidence that the glaciation was but slight as compared with that at lower levels; for around the well-glaciated parts other striæ may be found, even on the same slab, which appear to be confined to the upper parts of the quartz-pebbles that project from the surface of much of the rock. Even on these the direction of the striæ is clearly parallel to that of the more obvious groovings near.

Crossing into Swaledale we do not find much satisfactory evidence anywhere south of the Swale to prove which way the ice went. In Sleddale Beck (one of the northward-flowing tributaries of the Swale) boulders of limestone from a faulted inlier have clearly been carried northward; as, however, this limestone lies not far above the bottom of a deep valley radiating from the highest ground within ten or twelve miles, later glaciers might be supposed to have acted as the means of transport.

At Keldside, after a storm, striæ were laid bare from under drift almost in the bed of the river Swale; and these clearly pointed right across the valley in which the river flows.

To the north of this in West Stonesdale there is abundant evidence to prove that parts of the ice moved across the valley of the Swale and up the tributary valleys to the north. Many boulders of grey limestone, of a kind that does not occur in this area above a cer-

tain horizon, have been carried far to the north of the nearest rock of the kind in place, and borne up hill to a point considerably above that reached by any of the parent rock in the neighbourhood. One of these boulders occurred at Lad Gill, near the Tan-Hill colliery, at an elevation of about 1600 feet above the sea.

Other striæ pointing in a generally north-north-easterly direction are found on Whitsundale Edge, and on the north side of Bakstone Beck; these are proved to have been caused by northward-flowing ice, by blocks of Millstone-grit having been carried across the Beck northward to rocks lower in the series. No other rock of the kind exists in place nearer than some which occurs in Teesdale, with the exception of that which is faulted in the valley of the Eden at the foot of Stainmoor: this grit, however, is much stained by Permian influences, so that blocks of it may be distinguished at a glance from any of the Swaledale Millstone-grit.

At Tan-Hill colliery, and on a hill a little to the north of it named Grey-grits on the Ordnance six-inch maps, several well-striated rock-surfaces occur, with the scratches ranging in a generally north-easterly direction. The central line of watershed of Northern England passes through part of this ground; and although there is no marked kind of rock in the drift to show which way the ice-sheet moved here, it amounts almost to a certainty that it came from the higher ground to the south-west—because in the opposite direction the surface gradually slopes for miles to the north-east, and there is no high ground again in that direction nearer than part of the Durham end of the great ridge that extends eastward from Cross Fell.

To the east-south-east of the striæ-bearing ground just mentioned lies the head of the comparatively wide dale known as Arkendale. The upper part of this widens out and merges into the slightly undulating tract of moorland most of which goes by the name of Stainmoor. The hills on the north side of Arkendale Head bear sets of striæ which have a generally north-easterly direction; the form of the ground shows that the ice that produced these must have flowed right across the Dale and over the north side of it into the basin of the Tees. The striæ in the other parts of Swaledale included in the map do not call for any particular mention: most of them show clearly enough that, away from the influence of the great icy stream that flowed northward from the high ground about the head of the dale, the lower ice tended more or less to flow in the direction of the principal valleys.

The details of the glaciation of the Dale district have been dwelt upon at greater length here than their importance might at first sight seem to warrant, because it was desirable to prove where the ice sheet that swept across the hills and valleys of Eastern Lancashire had its line of departure. If this can be made clear, and it can be shown that another similar ice sheet started from the same line of high ground, flowed alike over wide dales and high fells, and finally crossed from the basin of the Swale into that of the Tees on Stainmoor, many of the difficulties that are met with in accounting for the distribution of the Eden-valley drifts will be removed.

As it is here taken for granted that the glaciation of the Dale district was accomplished by a sheet of land ice of great thickness, none of the arguments which have been used to establish that point has been brought forward again. Mr. Tiddeman has proved its existence clearly enough in much of the country to the south of Swaledale; as, therefore, the glaciation of the Dale district to the north of the ice-shedding line resembles in every respect that to the south, there can be no reasonable doubt that they are both the results of one and the same cause.

If we now turn to the northern part of the country immediately to the west of the line marked A, taking up the evidence where it was left at the north-east corner of the Howgill Fells, we find that the drift on the limestone escarpment at Ash Fell is largely made up of Silurian stones, most of which have probably come from the Howgill Fells. Among these occur a small proportion of Old Red stones that may have been derived from the strip on the south side of the Lune. In following this drift towards the north we find the Silurian and Old Red stones becoming less and less common; and to the south of Kirkby Stephen they seem to be quite lost in the great accumulation of drift from the limestone country to the south. Just at this point, however, we meet with the Brockram, of which not a fragment has been found in the drift to the south of its present area of outcrop. A little distance to the north of its southern margin it begins to occur in the drift, glaciated like the stones that it is associated with, and from that line northward it is characteristic of the Eden-valley drifts over a large area.

It has been before pointed out that none of this rock in place lies above the 700-foot contour-line; but in following it in the drifts, in proportion as we advance towards the north-east, so we find it getting higher and higher, until, in the drifts that lie on the great line of watershed, it occurs at 1300 feet above the sea, or very nearly on the summit of the lowest pass of Stainmoor. There are other instances (to which reference will presently be made), in which the Brockram occurs at much higher levels.

Setting aside for the present any consideration of the evidence collected in Swaledale, it will be well to consider one of the only two theories of any value that have been advanced to account for the transportal of the Eden-valley drifts over Stainmoor.

It has been mentioned that none of the Brockram in place lies above the 700-foot contour-line, while the lowest pass of Stainmoor that any of it has gone over is, in round numbers, 1350 feet above the sea; that is to say, it is 650 feet above the highest rock of the kind in place. If it was carried over imbedded in floating ice, we shall be obliged to suppose that all the Brockram that went over Stainmoor was first frozen into the ice while the sea-level stood between the present 400- and 700-foot contours, and then that it was detained everywhere just a little to the north of the southern margin of the rock in place, until the relative levels of land and sea changed another 650 feet, after which the ice-rafts floated over and began dropping their burdens as they passed eastwards towards the

vale of York. Probably most geologists will consider such a combination of circumstances so very improbable that they will reject the ice-raft theory as entirely untenable.

It is perhaps unnecessary to bring forward any other arguments to prove that the Brockram cannot have been transported by floating ice in any form.

It has been suggested that the difficulty might be lessened if it could be proved that there had been a considerable upheaval on the escarpment sides of the great faults in Postglacial times—in other words, if it could be proved that in Glacial times there was not so great a difference between the relative levels of the Stainmoor passes and the Eden valley as there now is. That no such Postglacial upheaval can have taken place is clearly enough proved by the fact that wherever the drifts that contain Brockram have lately been removed from the rock, this is always found to be striated, if the rock is of such a kind as to receive and retain scratches; and these glaciated surfaces are found at nearly equal elevations on both sides of the faults, often within a few hundred yards of the lines of disturbance. In addition to this the long mounds of Brockram-bearing drift extend uninterruptedly across the faults in such a way as to show that there cannot have been much, if there has been any, movement on one side or the other of the faults since the drift-mounds were deposited. Lastly, there is nowhere a rock-terrace, even of a few feet, on the escarpment sides of the faults; on the contrary, wherever the rock-surface is seen, it forms a continuation of the features on the other side of the line of disturbance. Denudation in Postglacial times will not account for this, because the drift-mounds before mentioned have been left in what must be very nearly the shape and size they had after the last trace of the ice sheet disappeared.

If it be conceded that the Brockram cannot have been transported by any form of floating ice over the Stainmoor passes, we are bound to accept the only other theory that will meet the requirements of the case, and conclude with Mr. Croll that here also a great sheet of land-ice has been at work.

The numerous striæ that have been found on the part of Stainmoor over which the Eden-valley drifts can be shown to have passed, indicate clearly enough in which direction the ice was flowing; a glance at the Map will show that they range nearly at right angles to the present lines of equal elevation; in other words, they point the shortest way to the summit. What yet remains to be accounted for before the land-ice theory can be adopted, is the agency that caused the Eden-valley ice sheet to move, as it has clearly done, from west to east—up hill, instead of along the ordinary lines of drainage of the country. Fortunately we have not far to seek for the required evidence.

Hitherto no mention has been made of any of the rocks that are associated with the Brockram in the Stainmoor drifts. If any thing definite can be made out respecting the means of transportal of any one of the kinds of rock in the drift, it is clear that all the stones

that occur in the same way in the same beds of drift must necessarily have been carried thither in the same way.

In the northern part of the area included between lines marked A and B on the map (Plate II.), well-glaciated stones from the "Green Slate-and-Porphry" series occur here and there in the Brockram-bearing drift. Most of this rock is quite unlike any of the Upper Silurians of the Lake district; these stones must therefore have come from the west.

Advancing a little to the north, we cross the southern line of dispersal of Shap granite. This line is marked B on the map, and does not differ materially from that drawn by Prof. Harkness in his paper on the distribution of Shap-granite Boulders*. It has been generally supposed that Shap-granite blocks are to be found only on the surface, and do not anywhere occur in true Glacial drift. But Prof. Hughes long ago found many unmistakable examples in the drift of different parts of Westmoreland, and the writer has since detected others; in fact, as has been pointed out by Mr. Gunn, of the Geological Survey, the number of Shap-granite boulders exposed in the drift bears as great a proportion to the superficial area of the sections of drift that are exposed, as the surface-blocks, numerous though they are, do to the whole area of the country wherein they occur. Well-glaciated boulders occur in abundance immediately to the east of Wastdale Crag itself; and although none of these are clearly seen in the drift itself, because no good sections are yet laid open, yet the fresh and unweathered appearance of those that occur at the surface speaks plainly enough of the lateness of their removal from the drift in which they were imbedded.

There is no need here to particularize all the localities in the Eden valley where Shap-granite boulders occur in drifts of the stiff-clay-matrix and glaciated-stone type. It is sufficient to state that it does occur as glaciated blocks in drift of this character, and that it is often associated with glaciated fragments of Brockram.

Passing now to the north of the line marked C on the map, in the country around Brough, the drift yields Brockram, Shap granite, and well-glaciated stones of all the Lake-country rocks that were mentioned as being made use of as tests of the direction taken by the drift. These stones occur in the drifts all the way from the summit of Stainmoor to the parent masses.

Perhaps the most remarkable boulders are those (nearly always small ones) of the syenite of Ennerdale, of the particular variety which Mr. Ward has shown to occur as boulders all the way from Buttermere to Cocker-mouth. Mr. Ward does not think that any of this rock has come down the dales to the east of that in which the river Cocker flows; so that its occurrence in the till on Stainmoor affords a very valuable piece of evidence, the importance of which will be shown further on.

Between the lines marked C and D respectively, the drift containing the stones above mentioned has in addition a number of glaciated boulders of rocks from Kirkeudbrightshire and Dumfries-

* Quart. Journ. Geol. Soc. vol. xxvi. p. 517 (1870).

shire. Through the courtesy of the Messrs. Newall of Dalbeattie, the writer has been enabled to identify some of these with the grey granite which is now being so extensively quarried in the neighbourhood of Criffel for ornamental purposes; and Prof. Geikie of Edinburgh has spared the time to look over and name a box of stones which could not be traced to any rock in the Lake district, thereby enabling the writer to identify many of the far-derived stones in the drift, and affording a tolerably sure clue to the course taken by the ice. The result is that the writer has been enabled to prove the existence of great quantities of the drift from the south side of the Scottish southern uplands in the Eden valley, up to the top of Stainmoor itself. The stones are smaller and are less common as we advance towards the head of the valley; but there they are, glaciated, and associated in such a way with the boulders from sources nearer at hand as to leave no doubt that these Scotch boulders too were carried up to the summit of Stainmoor by the same stream of land-ice that bore the Ennerdale syenite up the Eden valley and over Stainmoor, instead of following the course it would take under ordinary glacial conditions, and moving westwards towards the low ground of the Solway.

Line D, coinciding in great part with the foot of the Cross-Fell escarpment, approximately represents the northern boundary of the Shap-granite drift; and beyond the area in which this rock occurs, the line represents, as nearly as can be made out at present, the north-eastern limit of the Scotch drift in the Eden valley above Brampton*. A glance at the course taken by the stream of Scotch drift ice will show at once that it had precisely the direction that, on its meeting with the stream from the western side of the Dale district and the Howgill Fells, would cause the combined currents to take the direction which the striæ on the slopes of Stainmoor, and the direction of boulder-dispersal, show that the ice had there.

In considering the causes that impelled the Scotch drift up the Eden valley, we have to bear in mind that to the east of Carlisle great quantities of the same drift have gone over the watershed between the Eden and the South Tyne eastward to the North Sea, and that therefore the transporting current seems to have moved in a generally easterly direction over the low ground about Carlisle until it reached the north-west corner of the Cross-Fell escarpment, against which it split, the southern half coasting along the escarpment itself, while the other passed into the valley of the South Tyne. The general direction taken by the ice sheet at the north-west corner of the Lake district seems to have been about N. 15° W. or N. 20° W. Eastward from this part the direction becomes more northerly; and finally, if we may judge from the form of the ground about Hawes Water, the course taken by the ice there must have been about N. 25° E., a direction which the map shows was maintained from near that part up to the edge of the Dale district.

If we can trust the evidence derived from the direction of trans-

* Since this paper was written I have found far-travelled boulders some distance to the north of this line, near Melmerby.

portal of the Scotch boulders, the ice from Kirkeudbright and Dumfries must have flowed across the Solway in a nearly south-easterly direction, as thousands of boulders from the Galloway granite are scattered over the north-west of Cumberland. Such a stream of ice flowing in a south-easterly direction from Kirkeudbright, meeting with the opposing current from the north-west of the Lake district, must have resulted in the sending off of a combined current having a direction nearly magnetic east. About Carlisle the northern part of this stream must have had its direction again modified by the outflow from the local ice of the high ground between Eskdale and Teviotdale, which would cause it to take a turn still nearer to the east, while the southern part of the stream would be forced against the Cross-Fell escarpment and compelled to flow in a direction nearly parallel to it.

Once fairly in the Eden valley the slightest advance towards Stainmoor placed the upper part of the Scotch ice-stream more and more within the influence of the Lake-district ice, until, on meeting with the powerful north-easterly flow from the western side of the Dale district, the current was turned towards the comparatively low part of the escarpment near Brough and forced over on to the eastern side of the watershed.

It can hardly be doubted that the northerly line of fells ranging through High Street to the eastern side of the foot of Ullswater, backed up, as it is, by a still higher range extending from Helvellyn towards the high ground about the Caldbeck Fells, must have exercised a very considerable easterly impelling influence upon the upper parts of the Eden-valley ice. The fact that the striæ found on these fells show that the ice moved in the main along the valleys does not at all disprove the existence of higher currents flowing in other directions.

It has been remarked that one of the greatest difficulties we meet with in trying to account for the drifting of the boulders over Stainmoor is that many of the ice-markings seen in the Eden valley are plainly right across the path taken by the drift. Prof. Ramsay's theory that there were currents flowing in various directions at different levels in the ice-sheet over any given spot helps to explain not only this, but, as will be shown further on, much else connected with the drift that would be difficult to explain in any other way. As before observed, much of the ice that filled the Eden valley came from the high ground to the south; and the easterly drifting of the boulders has been inferred to have resulted from the meeting of the northerly-flowing local ice with the stream that flowed parallel to the escarpment. Therefore it is probable that at low levels the local ice would be pressing outwards far to the north of the currents which, in the higher parts of the great stream, were flowing eastwards full of boulders. In this way it is easy to explain the existence of the scratches at Gathorn near Crosby Ravensworth which are referred to by Prof. Harkness in his paper on the distribution of Shap-granite Boulders. These striæ lie at, or near, the bottom of a valley which lay exactly in the path of the ice coming from the Howgill Fells; so that it is not improbable that an

undercurrent of local ice flowed northwards along this hollow, while at higher elevations the main stream conformed to the general direction taken by the Eden-valley ice.

The influence of the local ice upon the Eden-valley stream generally is well shown near Tebay, where the map (Pl. II.) shows that the southern boundary of Shap-granite dispersal has been deflected a long way to the south, because just about there a considerable depression exists, and the local ice does not seem to have risen high enough to keep the Eden-valley stream so far from the Silurian country as it has done in the neighbourhood of higher ground. So too with the same boulders in the valley of the Bela. Here the north-easterly-flowing ice passed over a deep valley in which the lower layers of the ice were sheltered from the northerly impelling force that affected the upper part; and in consequence, the south-easterly-moving Eden-valley ice, meeting with less cross-resistance, flowed up the valley, striating the rocks and forcing the Eden-valley drifts up the ravine. This is still more evident with the Brockram drift in the same valley; the map shows that there is a deflection of the boundary-line of this drift two miles and a half out of the course it has taken to the south. It is as well to mention that this does not rest upon negative evidence, because the numerous drift-sections to the east of the line (A) do not yield a single stone that may not have come from the Carboniferous district to the south.

We have therefore in these cases clear proof that while the higher strata of the ice sheet were moving steadily forward in a north-easterly direction, the lower layers, being sheltered from much of the northerly impelling force that urged on the upper strata, and being at the same time acted upon by a like amount of south-easterly impelling force as affected the ice to the north and south of the Bela, were forced in a direction nearly at right angles to the course taken by the upper part of the ice sheet over the same ground.

Only some such explanation as that given by Prof. Ramsay will account for the fact that while the ice near the low ground in the Howgill Fells and the adjoining parts of the Dale district was shed nearly along the line indicated by the dots on the map, some of the higher strata moved in directions nearly at right angles to the course taken by the underlying streams. It is impossible to give any satisfactory explanation of the striæ on Swarth Fell and Baugh Fell if they were not caused by ice flowing from the high ground at the head of Mallerstang. It has been shown that in Mallerstang itself the drift moved towards the north—perhaps because the ice had no other course open to it; but at higher levels, where there were fewer obstructions, the ice would flow everywhere away from the highest ground. That the Baugh-Fell, and especially the Swarth-Fell striæ were produced by ice coming from the head of Mallerstang seems to be almost proved by Prof. Hughes finding Carboniferous sandstone in the drift on the north-western side of the highest ground of the Howgill Fells. Most of the adjoining Carboniferous Fell-tops are higher than any part of the Howgill Fells; it is therefore quite likely that some of the higher strata of

the Dale-district ice, laden with Carboniferous fragments, flowed over the Howgill Fells towards the lower ground of the upper part of Lunedale.

Owing to this diversity of directions taken by the various strata of the ice over any one place, it is next to impossible to draw any line that shall indicate precisely where the line of shedding was: that represented upon the map (Pl. II.) must be understood to be an approximation to the shedding-line of only the lower part of the ice-sheet thereabouts.

The instances of cross-glaciation mentioned as occurring in the Eden-valley seem to show that the component forces that resulted in the easterly turning of the Eden-valley ice-stream must have been very nicely balanced; so that where a stronger current from the south set in, the Eden-valley ice was sent further to the north, and, on the other hand, where the local northward-flowing ice exerted less power, the Eden-valley stream advanced towards the line of ice-shedding. In this way we can easily account for the fact that none of the Eden-valley ice, after crossing Stainmoor, found its way down Arkendale into Swaledale. There is nothing whatever in the form of any of the surrounding ground to prevent a marine current from passing that way; on the contrary, every thing seems favourable for a dispersal in that direction; but, as a matter of fact, there is not a single fragment known of any rock in the drifts about Arkendale Head that may not have been derived from the rocks near at hand. One can understand this easily enough when it is known that a thick sheet of ice from the Fells at the head of Swaledale flowed right across the head of Arkendale, and kept the Stainmoor drifts a long way to the north of the line they would have taken had no such ice-sheet been in existence; but how are we to explain these facts by any theory of marine action?

No reference has yet been made in this paper to the dispersal in a southward direction of Shap granite in the basins of the Mint and Lune on the south side of the Lake-district watershed. This was almost certainly owing to the lowness of the ground between the Shap-granite area and the Howgill Fells, in consequence of which the local ice had not sufficient bulk to keep the upper part of the Eden-valley ice-stream far enough to the north to prevent its overflowing into the area south of the watershed. The striated rock-surfaces indicated on the granitic area itself seem to bear out this conclusion, as the rounded sides of the rock face to the north, as if the ice came from that direction. There seems, however, to be some reason for thinking that this cannot always be relied upon as a test of the way the ice flowed, as in one instance, in Garsdale, where it seems tolerably certain which way the bulk of the ice went, the rounded surfaces face away from the source of the drift. This may be due to a local variation in the ice-current; but at any rate it will serve to caution us not to trust entirely to the appearance of the dressed surface as evidence of the direction of flow of the ice.

It seems that there are but few glaciated districts that afford an opportunity of making an approximation to the thickness of the ice

that covered them at the climax of the Glacial Period. But one may venture to assume that the very slightly glaciated rock-surfaces above the 2200 contour-line on the western side of the Dale district prove that the ice cannot have had a much greater thickness than the height of the highest ridge of land over which it can be proved the ice-sheet flowed. Apart from the evidence of the limited amount of glaciation on hard rock-surfaces, we seem to get other evidence in favour of this supposition in the fact that the soft shales and thin interbedded flagstones that occur on the highest ground of the Dale district nowhere exhibit any of that remarkable surface-crushing and contortion so often met with on the surface of beds of the same character at lower levels. After considering all the evidence, there does not seem much probability that the surface of the ice of the Dale district ever rose much above the 2300 or 2400 contour, if it ever was so high as that. If we assume that the ice reached an elevation of 2400 feet above the sea about the line of departure, the fact that it flowed away to the north would seem to prove that the Eden-valley stream must have had a lower surface. Had it been higher, some of the ice from the Dale-district Fells would have been ponded back, and must have flowed southwards from the Eden valley. It is clear that the lower strata of the ice did not do so; but there is only the negative evidence that no Eden-valley drift-boulders have gone south of line B anywhere, and that the ground rises more than 1500 feet above the sea, to prove that the upper part of the ice did not flow southwards from the Eden valley.

From what has been stated about the causes that impelled the Eden-valley ice over Stainmoor, it will be seen that the thickness of the ice that came from the southern uplands of Scotland need not have been greater than the local ice of the Lake district. Mr. Ward finds no striæ above the 2500 contour-line. As this ice flowed steadily away northwards, it would seem to prove that in the north-western part of the Eden valley the Scotch ice cannot well have exceeded 2400 or 2500 feet in thickness—a conclusion which harmonizes well with that derived from the investigation of the Dale-district glacial phenomena.

Glacial erosion.

Such a sheet of ice as that with which the area treated of in this paper was enwrapped must have exercised a very powerful denuding force upon the low-lying parts of the country; but there seems as yet no satisfactory means of determining what thickness of rock was removed from any given spot. One thing, however, is tolerably clear: although the great ice-sheet did undoubtedly deepen many valleys where these happened to lie in its course, there are other cases in which it can be shown that the ice has tended to make them relatively shallower by grinding down the intervening ridges, in districts where the lower parts of the ice were forced across the lines of drainage.

In one part of the Eden valley, near Crosby Garret, we have satisfactory proof that the deep hollow in which Scandal Beck now

flows was not initiated by glacial action, although its direction so nearly coincides with that of the flow of the ice there; for we find patches of Permian rocks in the very bottom of the valley, proving beyond all doubt that a ravine existed there in pre-Permian times.

It may well be doubted whether many instances of considerable valleys which have clearly originated by glacial action can be pointed out, as it is nearly always difficult, if not impossible, to prove that they are wholly the work of ice. The evidence seems rather to prove that the ice ground down most of the minor inequalities of the surface, and thereby tended to efface the preglacial channels of the lesser streams, and that, where the pressure and rate of flow of the ice were nearly uniform over large areas, it tended to level these into plains instead of ploughing out great parallel furrows in them.

In those parts of the Dale-district valleys where the lower strata of the ice can be shown to have flowed nearly along the windings of the dale, the alternations of hard and soft beds that make up the dale-rocks have given rise to more striking terraces than are to be found in other parts where the ice is known to have crossed the lines of outcrop at a greater or lesser angle. Where the direction taken by the ice has nearly or quite formed a right angle with the line of outcrop, we generally find that the characteristic surface-features of the dale-rocks are entirely wanting; and even where there are thick beds of limestone, the long lines of swallow-holes that almost everywhere else accompany beds of limestone in the dales, are generally absent. In the terraced parts of the dales, no matter what may be the width of the terrace, the swallow-holes, save an occasional one here and there, are only to be found along the line where the usually soft overlying beds come on. In no instance yet known to the writer do these swallow-holes extend far from the inner margin of the terrace towards the scar at its outer edge. In addition to this it is unusual to find the limestone of the lower terraces much more weathered, or wider joint-fissures developed in it nearer the scar-margin, than may be found all over its surface up to the swallow-holes.

In considering the causes that may have helped to shape these terraces, we may leave marine action entirely out of the question, because they are confined to particular beds of rock, and go with them through all their variations of dip and elevation. Streams rarely run along the foot of the scar or along the inner margin of the terrace; and those that do so are so small that they cannot remove any appreciable quantity of weathered debris from the rock above. Springs can do little else than undermine the part of the scar from which they issue, and in that way cut it back into a notch; the greater the number of springs issuing from the base of a scar, the more is it notched and changed in outline.

Landslips can effect but very little. It is true that great masses of rock are frequently removed from the scars in this way; but the crescent-shaped hollows that are left, and the great heaps of fallen material remaining at the foot of the scar, are very different from

the sweeping curves and generally unencumbered lower slopes that are usually seen about the lower terraces. Some of the scars are more than 1000 feet above the bottom of the adjoining valley ; and as no stream could possibly flow along the slopes in such a way as to carry off the talus from the scar, unless the valley were shallower by several hundred feet than it is at present, river-action cannot be taken into account, unless it can be shown that in the north of England, with a high rainfall, a river can cut its channel down more than 1000 feet while the scars above only recede a few feet from the line at which they were first formed. Many of these scars, too, can be shown to follow the undulations of the beds, so that the top of the scar at one place is often much lower than the base at another a few hundred yards off.

Ordinary weathering in nearly every case is tending to cut back some of the most precipitous scars into rounded slopes. Where the scar is of limestone it is often banked up by a talus of small weathered chips detached along the joints and bedding-planes from the higher part of the scar ; and it is obvious that, unless a stream is at work below carrying off the weathered material, the talus will accumulate, protecting the lower part, while the top of the scar weathers back into a low slope, the result being a small escarpment quite unlike the bold lines of scar seen in the dales.

Professor Hughes pointed out to the writer in 1868 that the sub-aerial agents just referred to were inadequate to produce much of the present form of the ground in the dales, and that land ice must have had a large share in bringing the rocks into their present shape.

When we know that in the upper parts of Wensleydale and Swaledale, and in some of the adjoining valleys, the ice must have been at the least 1600 feet in thickness, the facts mentioned above become intelligible. It is easy enough to understand how such a mass of ice—charged throughout with stones of all sizes, and flowing between fells which are made up of alternations of hard and soft beds lying nearly horizontally—would cut with most ease into the soft beds, so as to leave much of the less easily eroded rocks standing out as terraces and scars. This explains how it is that the swallow-holes are confined to the inner margin of each terrace, and that the terrace is nearly uniformly weathered all over. All the preglacial terrace, swallow-holes, joints and all, was carried away by the ice ; and when this disappeared a new surface of rock was left for the weather and streams to act upon.

The next hill-slope above the terrace has been cut back so little in Postglacial times that it is often not more than a few feet from the centre of the swallow-hole—that is to say, from the position in which it was left at the close of the Glacial period.

Glacial markings are occasionally met with on these terraces close up to the inner margin, affording another proof that they are nearly as the great ice-sheet left them.

This theory helps us to understand how it is that on some of the hill-slopes terrace above terrace exhibit so remarkable a conformity

of curvature, thus plainly enough pointing to the oneness of their origin. We can also see why it is that these curved lines of scar are so frequently opposite to the mouth of some large branch dale, the ice from which compelled the main stream to curve against the opposite bank.

If now we turn to those parts of the dales where the ice has flowed up the cross valleys and across the lines of outcrop of the beds, instead of the terraces and scars observable in other parts of the dales, we find the hill-sides ground into smooth slopes, with nothing at the surface to mark the diversity in lithological character of the rocks beneath. In the case of the dales on the south side of Wensleydale above Hawse, wherein Snaizholme Beck, Widdale Beck, and Duerly Beck flow, we have some instances of regularly curved hollows just at those points where the form and direction of each dale would cause the ice from the high ground to the north to take a slight curvilinear motion, which resulted in the grinding-down of preexisting irregularities into sweeping curves. Looking at the beautiful "coun" at the head of Snaizholme Beck, one cannot help being convinced that nothing but ice could produce such a result. Springs, as before pointed out, tend rather to cut the rock back into notches; and, moreover, in the dale rocks they act only along certain definite lines. Streams act still more powerfully in forming ravines, quite unlike any of the smooth concave hollows here referred to. And, lastly, the ordinary action of the weather tends to enumber such slopes with the ruin of the higher rocks. But in the instances here referred to comparatively little weathered material lies on the hill-sides; and in the case of the Snaizholme coun the slopes are nearly bare, except where a thin covering of drift clings to them and hides the rock.

Many other instances of similar couns could be adduced; but one other instance from the Dale district will suffice. It was pointed out above that the ice-sheet crossed Dentdale in a south-westerly direction in flowing towards Lunedale. Part of this stream, as the ice-markings show, passed in a south-south-westerly direction up Dibdale. At the head of the dale the stream divided against the Nab, one branch going off to the south-west and turning against Gragreth, the other taking a south-south-easterly course and curving against Wherside. The result is that we have two couns which, if not so striking as the Snaizholme coun, show a greater height of curved surface. That on the west side of Wherside can be traced upwards for at least 1000 feet—the curves opening with great regularity, from one of a radius of about a quarter of a mile near the bottom, to the curved line of grit scar, at the top of which the radius is about a mile.

When we compare these couns with the other rock-features of the district, there is seen to be a perfect gradation from a nearly straight line of scar, through others more and more curved, to such a coun as that at the head of Snaizholme Beck.

In many other places where the form of the ground has caused the ice-stream to turn in its course we find more or less perfect

examples of these concave rock-surfaces; so that it is difficult to avoid the conclusion that out of the Dale district the same causes have been at work, producing these cup-shaped hollows among the fells wherever local circumstances compelled part of the ice-sheet to move in a curve.

In the numerous instances in every mountainous district where the upper parts of the ice would be influenced more by the form and direction of the adjoining high land than by the general trend of the valleys, there is a strong probability that wheeling movements were communicated to parts of the ice. The axis of rotation would of course vary in direction according to local circumstances: in some cases the ice may have moved downwards in a curve as a kind of undertow to the glacial stream that was crossing a col into another valley; but in the majority of cases the tangential motion may have resulted from the meeting of cross currents in, or nearly in, the same plane. There can be little room for doubt that any such eddying of the ice, charged throughout with stones, must have operated very powerfully in smoothing preexisting hollows into more regularly concave coums; and it is perhaps hardly out of the question that in soft or easily eroded rocks the long-continued action of the ice may have excavated many such hollows where nothing of the kind existed in preglacial times.

Origin of Drift-deposits.

Before discussing the origin of the Eden-valley drifts in any detail, it will be well to make a few general remarks upon the various deposits which by one cause or another were left at the close of the Glacial Period over the greater part of the area treated of in this paper.

In the Dale district the order of the drifts is as follows, beginning with the lowest:—

No. 1. Stiff clay, full of well-glaciated stones, apparently devoid of stratification; usually lying in the bottoms of the higher parts of the main valleys, and generally found along the whole length of the bottom of the branch dales, except where these are far from the head of the principal valley.

No. 2. More angular drift, containing fewer scratched stones and having a more sandy matrix than No. 1. In the higher parts of the valleys it becomes still more angular and loosely aggregated in proportion as it nears the highest ground. It frequently extends up to or above the 1800 contour in the form of an irregularly sloping plain; but thin patches of drift of the same character may be found nearly up to the tops of the fells, where it seems to pass into a kind of surface-wash in which an occasional scratched stone may be found. This is not merely a weathered part of No. 1, but maintains its characteristics to a great depth from the surface, at which no larger proportion of glaciated stones can be found than are to be seen near the outside of the deposit.

No. 3. Still more angular drift, quite devoid of stratification, very

loosely aggregated, and free from clay; scratched stones very rare; big angular blocks occur in abundance. It generally forms very mounded ground high up above the valleys, and has not been detected within a radius of several miles from the highest part of the Dale district. It has altogether a very morainic look; and although in the mass it may be separated from No. 2, smaller deposits of it are distinguished with difficulty; and such sections as exist seem to show that there is a gradual passage downwards into No. 2.

These three divisions are seldom sharply defined; and although one or two sections seem to show that No. 2 lies on an irregular surface of No. 1, it is impossible to draw a sharp line between any of them over large areas. In the bottoms of the valleys, at variable distances from the nearest line of high ground, we find thin seams of finely stratified sand alternating with sheets of tough finely laminated clays with and without included stones, and associated with occasional beds of gravel, of which a few of the stones bear half-obliterated glacial striae. These are overlain by more or less clayey beds of No. 2, that frequently show obscure stratification near the base, and are clearly seen to occur above the till, No. 1. The sand and gravel passes down into No. 1 and up into No. 2 in such a way as to point to the oneness of origin of the whole.

Further from the head of the dale sections in the low-lying drift mounds show that, on the whole, the proportion of washed materials increases towards the low end of the valley, thicker beds of sand come in, the glaciated stones become more and more waterworn, and the overlying beds referred to No. 2 become cleaner and show more decided traces of bedding. Still lower down the valley mounds of sand and gravel, with included seams of clay and hardly any glaciated stones, come in: the mounds themselves are often several hundred yards apart, and sections occur only at irregular and often distant intervals; but the similarity of the contents to those of the thinner deposits seen higher up the valley, and the close resemblance in the form and disposition of the higher and lower mounds, would seem to lead to the inference that they are in some way the work of the same agency, although it is impossible to prove it.

Many of the thin sheets of laminated clay referred to above seem as if they had been originally thrown down at considerable angles, as the seams of sand above and below do not always show any sign of contortion. In so many instances have these sheets of laminated clays been met with inclined at various angles, that it seems quite the exception to meet with any that are horizontal, unless the section is at a great distance from the head of the valley. In many cases, hereafter to be referred to, it is quite clear that the inclination of these beds of laminated clay is that of original deposition. This point being well established, it follows that the drifts in which these clays occur cannot have been deposited under water, and must therefore have their origin accounted for in some other way.

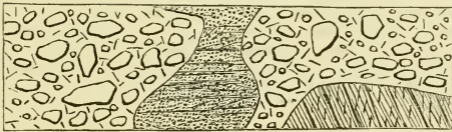
Hitherto all the cases of inclined or contorted strata in the drifts seem to have been regarded as clear proofs of the grounding of floating ice; hence it would follow that wherever contorted beds

occur, there the sea must have been in glacial times. It will be shown further on that this kind of evidence is, in many cases, at least equivocal, and that several other causes must have been at work producing the appearances in question. Some of the laminated clays contain angular and glacial stones; and in a few instances, where the lamination is not very evident, it is not easy to distinguish them from ordinary till.

In the dales the mounds of sand and gravel are found at intervals from near the highest place where sand begins to appear in the drift downwards towards the mouth of the dale; but they seem to attain their greatest development about the mouths of the larger tributary valleys. In proceeding towards the lower parts of the dales the gravel on the whole does not appear to become much more waterworn. This is probably due to the share the larger tributaries have had in contributing towards the contents of the gravel-mounds, so that it is not an unusual circumstance to find mounds of slightly washed gravel a long way below another part of the dale where the striae are nearly obliterated from most of the stones.

In one of the Settle and Carlisle Railway-cuttings near Horton-in-Ribblesdale the line has passed through a deposit of tough clay, full of glacial boulders, and quite of the character of ordinary till. In one part a flask-shaped deposit of finely laminated and false-bedded sand and thin seams of clean gravel occurs surrounded, certainly on three sides, by the above-mentioned clay-drift (fig. 1). There is

Fig. 1.—Section in the Settle and Carlisle Railway-cuttings near Horton-in-Ribblesdale.



Undisturbed nest of finely stratified sand and gravel in till. *r.* Rock.
Length 30 ft.

not the slightest sign of any contortion; and the deposit is clearly not due to river-action, because the sides of the nest close in rapidly above, and the railway-cutting shows plainly enough that the sand does not extend even as far as the western bank.

If this stiff clay full of glacial stones is part of a *moraine profonde*, how is this undisturbed nest of sand, which extends upwards for at least 10 feet, to be accounted for? The ice that this drift is supposed to have accumulated under cannot have been less than several hundred, perhaps it was more than a thousand feet in thickness over that particular spot; it is therefore obvious that the forward movement of such a mass a single inch must have resulted in

the kneading up of all the sand into the drift in such a way that every trace of stratification would be obliterated.

All the drifts mentioned above contain a far smaller proportion of clay than we should be led to expect, when we take into account how much shale there is in the dale-rocks. Taking them altogether, it would perhaps be rather an underestimate if the proportion of shale to the whole mass of rock in the area here treated of were set down at one half. Yet extensive deposits of drift may be met with, into the composition of which clay hardly enters at all. Even in the till, the most clayey of all, it is doubtful whether the proportion of clay to stones is any thing like that of the shale to the other beds.

Again, if we consider how large a proportion of limestone and of some of the finer and softer sandstones must have been ground into mud by the ice, it is not very easy to understand how any very large proportion of the drift can really be the *moraine profonde* of a great ice-sheet. An enormous quantity of clay must have gone out of the dales somewhere; and it certainly is not clear how the ice should carry away so much of the finer detritus of the rocks that it passed over, while it left the coarser parts behind. A possible explanation of this may be that the greater part of the stones in the drift may be but the remodelled result of the preglacial weathering of the dale-rocks—that, in fact, the drift is but a mass of glaciated stones originally derived from the old fell-side scree. The objection to this is, that wherever any bed of rock occurs of such a lithological character that it can be traced with some degree of certainty in the drift, it can almost always be proved that it has travelled many miles, in some cases even hundreds of miles, from the parent source—as, for example, the Shap granite, which has gone as far south as the Vale of Gloucester. What, therefore, is true of any marked bed of rock, must be equally true of all other rocks that have undergone the like amount of glaciation. It is therefore very unlikely that any large quantity of the old subaerial waste of the dale-rocks has been left anywhere near where it was when the ice first reached it. Judging by the distances other rocks can be proved to have been transported by the ice, the thick accumulation of preglacial surface-waste must have been swept away to great distances. Hence, instead of looking for traces of such detritus near the parent rocks on the eastern side of the watershed, we should rather expect to find them somewhere about the east coast, or in the North Sea, if there were many stones tough enough to withstand the effects of a transportal to so great a distance.

When we turn to the drifts of the upper part of the Eden valley, we find nearly the same order as obtains in the dales. The lowest drift of all is of the character of the ordinary till, a stiff clay of various colours, according to the kind of rock that most of it was derived from, and full of stones, most of which are well glaciated, and are generally of comparatively small size.

It is not always possible to distinguish the till from the deposit that overlies it. Occasionally, and especially in the vicinity of

low ground, the upper division is quite as clayey in the matrix, and contains as large a proportion of glaciated stones as the ordinary till. On the other hand, in the smaller valleys the clayey till seems to thin away, and to be represented by drift resembling that found under similar circumstances in the Dale district.

Wherever we have an opportunity of determining to which division any particular patch of drift belongs, we find that the higher drift contains the bigger and more angular blocks, and that there seems to be a larger proportion of far-derived boulders in it than has yet been detected in the lower division. But on this point one cannot always be quite sure, as, unless the section is very deep and kept quite clear, it is but rarely that the underlying beds can be examined. In the few instances in the Eden valley where a deposit answering to the true till is laid bare, it *has* yielded stones which have undoubtedly come from a distance. The other stones in it, although they have not travelled so far, have yet been transported long distances in precisely the same direction as those in the overlying drift.

The drift sections in Swindale, above Brough, afford good instances of this. At Swindale Head, at an elevation of about 1350 feet above the sea, a thin bed answering to the description of the till occurs under a much thicker mass of more loosely aggregated drift. A few of the ordinary Eden-valley drift stones occur in the upper deposit, most of them having a more local origin than those that are not so near the boundary line of the up-travelled drifts. In the tough tills beneath, we have a stiff clayey matrix of a deep red colour, which is derived from the wear and tear of the Permian rocks of the Eden valley. Among the stones several recognizable fragments of Brockram may be detected, thus proving that this till, like the very different upper drift, has moved upwards from the Eden valley, and that both drifts have moved in the same direction. It should be noted that this red till is nearly 700 feet higher than any of the red rocks from which it must have been derived.

The only exposures of the lowest drift on Stainmoor are in different parts of Swindale Beck. The numerous sections in the higher drift that is considered to be the equivalent of No. 2 of the Dale-district drifts, show that it has a tolerably uniform character nearly everywhere on the high ground. The stones in it vary as regards origin, according to the position of the mound where they occur. The mounds to the east of line A (Pl. II.) contain nothing but what might have been derived from local rocks. Between A and B the stones have come from a greater distance. Lines B and C enclose mounds which contain Shap granite and many rocks from the Lake country, in addition to others that have not travelled as far. And, lastly, the area included between C and D is that in which the drift includes detritus from the north of the Lake district, the various kinds of granite and other igneous rocks from Galloway, and a few perhaps even from the Lower Old Red Sandstone at the head of Nithsdale. Yet the general parallelism of the drift mounds, and their similarity in form and size from the lowest ground up to the highest point

where they occur, whether their contents have come from a great distance or are confined to detritus derived from rocks within the physical basin of the Eden, leave little room for doubt that they were all thrown down in the same way.

In the low ground at the foot of Stainmoor a few sections show that locally a threefold division of the drift obtains. The section at the scar alongside Swindale Beck under Brough Castle may be taken as typical, as no other so good is to be seen anywhere else in the neighbourhood. At the bottom of the scar the beck has cleared a deposit of tough red clay, with seams of red laminated clay, and including blunted and glaciated stones, of which a few are quite angular, and some big enough to be called boulders. About 20 per cent. of the stones are known to be from a distance, as unmistakable fragments from the "green-slate-and-porphry series" and other Silurian detritus occur; the rest seem to be of Carboniferous and Permian origin. As these, however, have no distinctive character whereby they might be referred with certainty to the rock of any particular place, some of them may have come from the north-west end of the Eden valley for aught that could be said to the contrary. No Shap granite nor any traces of Scotch drift could be detected, perhaps because the very limited area exposed gives one but little opportunity of making a fair estimate of the true percentage of far-derived stones.

The upper part of the till exhibits more distinct lamination, which is well shown by the presence of thin lines of sand and fine gravel, and, in the absence of these, by the unequal weathering of the alternate clayey and loamy bands in it leaving the tougher clayey laminae in slight relief. Where the beck washes beds of this kind it acts in much the same way, only that inclined and convex terraces several inches in width are developed in the laminated clays by the gentle washing of the stream. Obscure traces of plants occur on the bedding-planes of a few of these tough clays; but none could be got out perfect.

One cannot help being struck with the number of instances of inclined laminae of this fine clay, with and without stones, which are found; but from the top to the bottom of the scar not a trace of any thing like contortion can be found in any of them.

The slopes above the part of the scar where the till is seen are obscured for about 10 feet by slips from the higher beds; but it is said that courses of sand occur in it. Above this point the writer employed some men to clear the section up to the Castle. They laid bare about 25 feet of finely bedded straw-coloured sand, with lenticular seams of coarse and fine gravel, layers of stony clays, and occasional thin sheets of tough gutta-percha clays without stones. Near the lower part of the clearing the beds just mentioned alternate with irregular patches of stiff clay drift with glaciated stones in no way different from the ordinary till of the neighbourhood, except that they are not quite so red as the till seen lower down by the beck-side. The stones from the interbedded patches of till and those in the gravel seams have about the same percentage of far-

derived stones as occurs in the lowest bed. In the upper part of the section the same alternations of sand with beds of till were found; but in passing upwards the seams of gravel and sand become thinner, and the interbedded till gets thicker, until an almost undivided mass of clay-drift with glaciated stones and boulders up to 4 feet in diameter is met with. A large surface of this upper clay is exposed, and yields many subangular, blunted, rounded and glaciated boulders of Shap granite. Other rocks represented were two or three varieties of Galloway granite, blocks and fragments of the syenites of Carrock Fell, St. John's Vale, and Buttermere, as well as other Lake-country rocks in abundance, stained Carboniferous detritus from the Eden valley, and much Permian sandstone and Brockram.

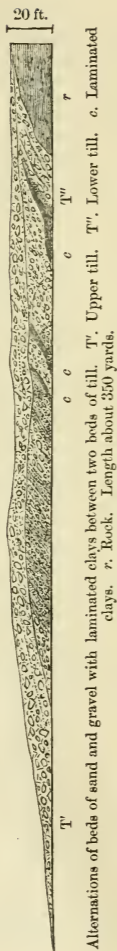
The mound in which these drifts occur is one of a great series of chains of drumlins which trend in sweeping curves from the lowest parts of the Eden valley, in one case nearly up to the Stainmoor watershed. Their direction seems to have been influenced in nearly every case more by the contour of the nearest high ground than by the direction in which the bulk of the drift was transported. In those cases, however, where the ice was guided in its course by the form of the adjoining high ground, not a few of the longer axes of the drumlins lie nearly in the same line that the included boulders have travelled in.

Here and there in the country below Brough, a section shows that seams of sand and gravel are interstratified with beds resembling true till; but, owing to the disconnected nature of the drift deposits, and the fewness of good sections, it is impossible to prove the identity of even the larger groups of sand and gravel in adjoining mounds. On the whole, however, it is tolerably clear that in the low ground the proportion of washed detritus associated with the clay-drifts is greater, and the signs of lamination in the clay-drifts more marked and more widely spread, in proportion to the distance from the head of the main valley.

It is nearly impossible to make out any definite order of succession in the drifts in the lower parts of the valley; the few sections seen show plainly enough that masses of sand and gravel pass into, and are interwoven with, clay-drifts in such a way as to defy any attempt at separation over large areas, although single sections may be indicated which do show a definite sequence. The larger branch valleys from the Lake district have further added to the complication by contributing quantities of more or less well washed drift, which lies in mounds the axes of which are often at right angles to the length of the tributaries from which the drift materials were derived, in such a way as to show that they were heaped up by the same cause that gave the adjoining drumlins their present form and position.

Much of the Eden valley below the 500-foot contour between Musgrave and Lazonby lies in two old rock-basins, the lower lips of which are formed by the Permian rocks that close in upon the river at Eden Lacy, and again between Lazonby and Armathwaite.

Fig. 2.—Generalized Section along the Settle and Carlisle Railway at Culgaith.



Alternations of beds of sand and gravel with laminated clays between two beds of till. T'. Upper till. T''. Lower till. c. Laminated clays. *r.* Rock. Length about 350 yards.

From evidence that will be referred to again it is almost certain that these great rock-basins could not have been filled with water to any depth while the drifts were being deposited, although the presence of alluvial terraces high above the present beds of the rivers of that part seems to point to the existence of a shallow lake of considerable extent in postglacial times, which may have been due to the presence of a barrier of drift mounds ponding back the natural drainage of the district. It is only referred to here because the rock barriers must have acted as bars to keep the sea out below the 450-foot contour, so that the absence of any thing at all resembling marine Boulder-clay above them is easily enough accounted for.

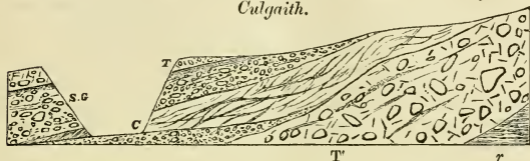
The cuttings now being made along the Settle and Carlisle Railway in the Eden valley afford some very instructive sections in the drifts. Above Culgaith there is not much that calls for any particular remark; but at the north-western end of the tunnels between that village and Longwathby the railway crosses the axis of a drumlin at a small angle, so that a very instructive section is laid bare. At the south-eastern end till, with the ordinary far-travelled boulders of the Eden-valley drifts, and obscurely stratified, is seen overlying beds of "marl" belonging to the middle division of the red rocks of the Eden valley. Overlapping the till is a series of alternations of diagonally bedded sands and gravels with finely laminated clays. Another mass of till, which is quite undistinguishable from that seen at the base of the series, covers all the beds from the northern end of the cutting to the solid rock. Fig. 2 will perhaps serve to make this clearer*.

The most remarkable point about the whole series of deposits is the singular uniformity of inclination of all the beds below the upper till that show traces of stratification. Some of the beds of laminated clay are seen lying at angles of from 25° to 30° , and in some instances at even higher angles than that, proving, beyond the possibility of a doubt, that they could not have been deposited under

* In the woodcut the gravels at the left hand of the section are represented as too highly inclined. The true inclination is nearly that of the base line of the overlying till.

water. All the beds incline more or less towards the lower end of the valley; but some small sections at right angles to the axis of the drumlin show that the false-bedding planes slope outwards towards the sides of the drumlin as well. Fig. 3 shows a small section

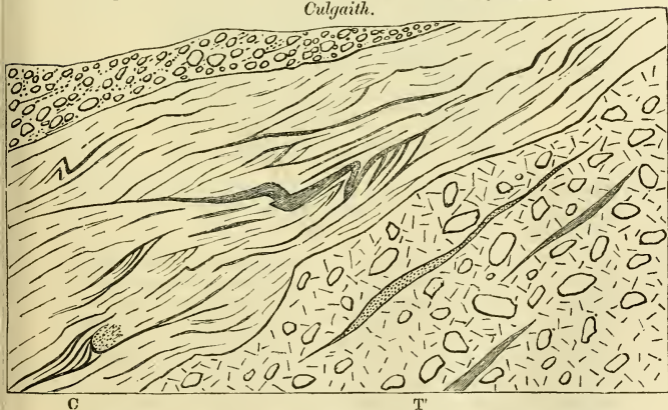
Fig. 3.—Section in the Settle and Carlisle Railway-cutting at Culgaith.



Section at right angles to the axis of a drumlin. T. Upper till. S.G. Sand and gravel. C. Laminated clay. T'. Lower till. r. Rock. Length 40 ft.

exposed by a slip of the beds nearly at right angles to the axis of the drumlin. The lowest beds seen were of till full of glacial stones from the lower part of the basin of the Eden and from Galloway. Lines of sand, and lenticular patches of laminated gutta-percha clays, inclined at angles of about 30° towards the side of the drumlin, serve to mark the stratification in this bed. Lying upon the till, with an uneven line of junction, is a series of finely laminated striped clays, having a thickness of from 3 to 9 feet (fig. 4). The

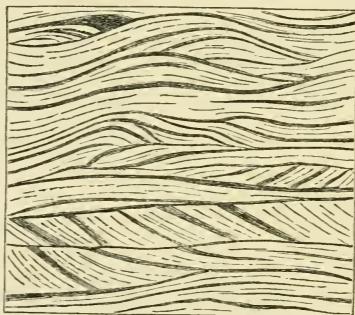
Fig. 4.—Section in the Settle and Carlisle Railway-cutting at Culgaith.



Part of No. 3 on a larger scale, to show the irregular lamination of the clays in the drift. C. Laminated clays. T'. Lower till. Length 12 ft.

oblique lamination is very well marked in this; and the angle of inclination of the laminae is nearly the same as that of the lines of clay and sand in the underlying till, and does not differ many degrees from the slope of the courses of sand in the overlying gravel series. It will be observed that the laminae of the clay are bent over and inverted in a few instances, but that the apparently contorted parts are surrounded by other parts of the same deposit that are clearly not disturbed at all. This will be referred to again presently. Few or no stones are found in the clays, which seem to be made up of fine laminae of clays of different shades of brown, and varying in lithological character from the finest clay to very fine micaceous sand. A clear section shows that these clays slope downwards to near the bottom of the railway-cutting, where a good section in them was to be seen at right angles to fig. 3. Figs. 5, 6, and 7 are taken from the bottom and the top of this deposit, as seen close to the rails. Figs. 5 and 6 exhibit the remarkably high incli-

Fig. 5.—Section in the Settle and Carlisle Railway-cutting at Culyaith.



Alternations of inclined, arched, false-bedded and crumpled laminated clays with others undisturbed. The darker stripes represent the darker-coloured clays. Length 12 in.

nation of the laminae of the clays, and show in the most unmistakable way that this high inclination is the result of original deposition, as it does not in every case extend into the beds above and below. In the lower part of the section there is no indication of any derangement of the beds. Near the top, however, the case seems far otherwise; for the beds appear to have been subjected to violent pressure, which has contorted them in such a way that the same lamina may be passed through vertically three, four, or even six times in succession (fig. 7). A closer inspection shows that to a great extent this appearance is deceptive, and that the contorted beds lie in the

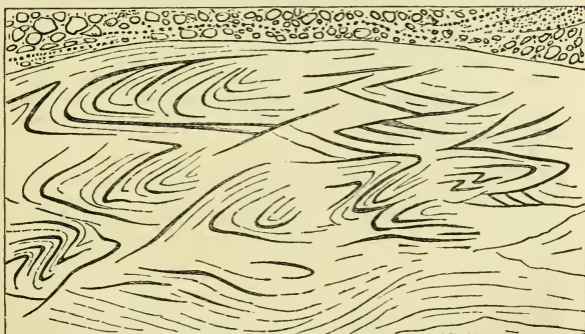
midst of what are clearly undisturbed layers of clay, in many cases only a few inches off from the contortions.

Fig. 6.—Section in the *Settle and Carlisle Railway-cutting at Culgaith.*



Alternations of disturbed, false-bedded, and nearly horizontal laminated clays. All the lines represent the darker-coloured beds of clay. Length 9 in.

Fig. 7.—Section in the *Settle and Carlisle Railway-cutting at Culgaith.*



Laminated clays contorted, between undisturbed strata. Length 2 ft. 6 in.

Thinking there was something about these apparently contorted clays that could not be well accounted for by the ordinarily received theories of their origin, the writer paid much attention to their mode of occurrence, with the object of discovering something that would help to explain the difficulty. After noticing that most of the sections which showed contortions like those represented in fig. 7 were upon faces which run along the "strike" of the false bedding, and that along sections parallel with the lines of highest inclination the contortions are much simpler in character, the writer

came to the conclusion that many of these apparent contortions may be due to the half-consolidated glacial mud slipping downwards to lower levels, and thereby causing a puckering of the beds. In this way certain parts of the clays must often have been thrown into sharp folds, and afterwards covered by laminae that had not participated in the movement; so that it is easy in such a case as this to account for the occurrence of laminated clays bent into the most fantastic forms, and yet lying between perfectly horizontal layers of the same deposit. When such a series of strata is cut along a face nearly at right angles to the line of highest inclination, we should find the outcrops following sinuous lines which would impart an appearance of contortion to the deposit more or less marked in proportion to the amount of puckering the clays had undergone in slipping down the slope upon which they were deposited. In this way if any of the foldings bulged more in one part than in another, such a section-face as that mentioned above would show rudely ellipsoidal lines of outcrop one within another, in much the same way, to use a homely illustration, as the coatings of an onion appear when a slice is cut off the side of it. Although it is not supposed that this explanation will account for all the contortions in the clayey beds associated with the till, and still less for those in the Boulder-clays of the maritime districts, it will be at least worth while to bear it in mind in examining sections of what appear to be contorted clays elsewhere*.

The other beds in the cutting do not call for any particular mention, as they contain beds of laminated clays in every way like those just described; and the whole series, as before remarked, is overlapped by the stratified upper till, without any very clear line of demarcation between.

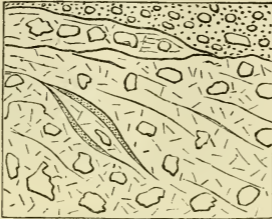
The first cutting north from Longwathby is through a tough maroon clay, containing a great variety of boulders up to 4 feet in diameter, including many from Galloway. Most of the stones are more or less waterworn; but the larger boulders retain a few scratches, and a few of the smaller are apparently as little rolled as those in ordinary till. The boulders are scattered throughout the clay without any indication of sorting, and the whole of the matrix shows faint traces of very irregular lamination, which is most evident on the freshly cut banks that have been washed by rain or by runlets of water from the top of the cutting. In this way the tougher laminae are left in relief, and show some remarkable instances of curved lamination, though there is no trace of any thing like contortion in the cutting (fig. 8).

Another section, about a hundred yards or so to the north, shows beds of sand and gravel flanking the clay of the last-mentioned cutting, and overlapped by another clayey drift. What principally calls for notice in this section is the occurrence of undoubted instances of contortion on a small scale, apparently caused by the

* Since the above was written I have stated my belief that these contortions are due, in great part, to the settling-down of the ice-sheet upon half-consolidated beds beneath. See 'Geol. Mag.' for Nov. 1874.

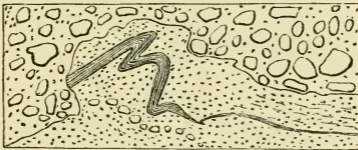
dropping of masses of coarse gravel into the soft beds of sand and loam beneath, so that the line of junction between the two deposits

Fig. 8.—Section in the Settle and Carlisle Railway-cutting at Longwathby.



Gutta-percha clays and fine sand false-bedded in lower till. Length 3 ft.

Fig. 9.—Section on the Settle and Carlisle Railway, near Longwathby.



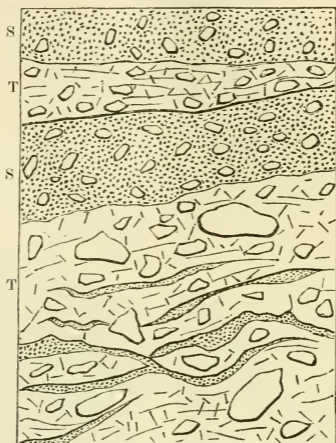
Contorted seam of loam in sand and gravel, unconformably overlain by coarser gravel. Horizontal length 6 ft.

of sand and gravel is very irregular (fig. 9). The false bedding is very marked in both these deposits; and the sheets of very clayey loam that occur seem, in a few instances, to follow the planes of false bedding, proving that they were originally thrown down on a slope.

No section occurs nearer than about another mile to the north, near Little Salkeld, where there is a considerable thickness of alternations of gravels, beds of sand with occasional seams of loam, and thin partings of finely laminated clays without stones. Some of the clays are clearly disturbed where heaps of gravel have been thrown down upon them; but in other parts of the section that are apparently undisturbed, beds of obliquely laminated sands have partings of tough gutta-percha clays between the lamination-planes. The stones in the gravel are nearly all well washed and rounded; but an occasional one may be found retaining traces of striæ. At the northern end of this cutting maroon clays, like those at Longwathby, come up from beneath the sands and gravels. The clays alternate with lenticular patches of water-worn gravel, courses of sand, and

thin sheets of laminated clays (fig. 10). Throughout the section the stones comprise a larger proportion of waterworn materials than

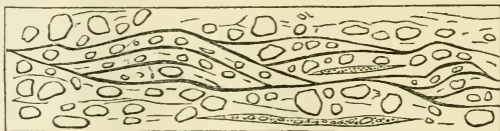
Fig. 10.—Section in *Throstle-Hall Cutting, Settle and Carlisle Railway*.



Intercalations of sand and gravel in till. T. Till. S. Sand and gravel.
Length 6 ft.

may be found in the clay of the same kind at Longwathby. The lamination of the gutta-percha clays is very well marked, and seems to run in no well-defined general direction; it is frequently inclined at several degrees from the horizontal, and occurs in such a way that it cannot possibly be the result of any thing but original

Fig. 11.—Section in *Settle and Carlisle Railway-cutting at Throstle Hall*.



Gutta-percha clays in lower till. Length 4 ft.

deposition. Fig. 11 will, perhaps, make this clear; it represents a length of about 4 feet of the stony clays of the cutting, over the

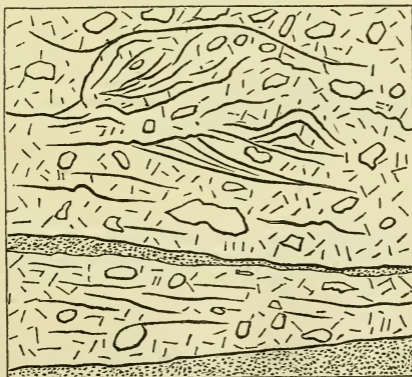
nearly vertical face of which runlets of water had removed the more sandy parts, so that the tough clays stood out in relief as curved and inclined shelves. It should be observed that this appearance is not confined to one particular part of the cutting, but may be found over the whole length of it where the clayey beds come in (figs. 12, 13).

Fig. 12.—Section in *Settle and Carlisle Railway-cutting at Throstle Hall.*



Gutta-percha clays in lower till. Length 15 in.

Fig. 13.—Section in *Settle and Carlisle Railway-cutting at Throstle Hall.*

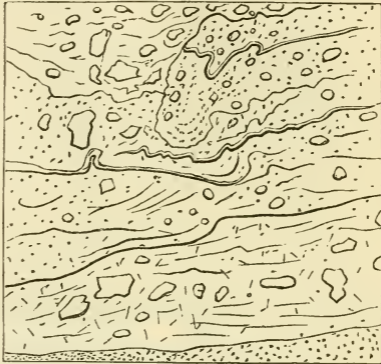


Irregularly stratified gutta-percha clays in lower till, with seams of soft sand. Length 4 ft.

The next cutting is about half a mile to the north, and shows sand and gravel-drift with loamy bands lying on a crushed surface

of Permian sandstone. The loamy bands are inclined at various angles, and seem to have been moulded over the rock-fragments in one or two cases; but on the whole it is not clear whether the inclination is original or not. The section is principally remarkable

Fig. 14.—*Section in Settle and Carlisle Railway-cutting near Armathwaite.*



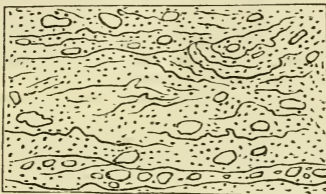
Puckered beds of loam in loamy sand full of stones. Length 4 ft.

for showing an apparent passage from undoubted glacial deposits, through crushed sandstone amongst the fragments of which the drift has been deposited, into unbroken rock.

Near Lazonby a deep cutting has been opened about a mile and a half to the north of the one just mentioned. Here there is a considerable thickness of alternations of clean sand, beds of loam, and irregular deposits of gravel, throughout the whole of which washed stones occur. These beds seem to lie directly upon the rock in more than one part of the cutting. A few thin bands of loamy clay with traces of lamination occur at intervals; but no unequivocal indications of original inclination could be found in them. The loamy bands are slightly crumpled throughout the section, and seem to show, by the way the foldings match with those below and above, that some compressing force was exerted against the beds after they were laid down. A considerable length of sections shows plainly enough that the beds have not been disturbed to any greater degree than that indicated by the very slight crumplings of the bands of loam. The stones comprise much Permian sandstone, but no Brockram, a large percentage of Lake-country rocks and Carboniferous Limestone, and many stones from Galloway, as well as a few which Prof. Geikie says remind him much of the Lower Old Red Tuffs at

the head of Nithsdale. As in other sections of a similar character, the stones are mostly waterworn; but they include a few that are quite angular, and an occasional one or two that have hardly lost any marks of glaciation. What is most noteworthy about the section is the close resemblance between this drift and the upper parts of the Upper Old Red in Birkbeck, between Tebay and Shap Wells,

Fig. 15.—Section in Settle and Carlisle Railway-cutting near Armathwaite.



Irregular seams of clay in stony loam. Length 3 ft.

and its even closer resemblance to the highest beds of the Brockram series, as, for instance, in Hilton Beck and along the banks of the Bela. The resemblance is further increased by the prevailing red colour of the drift-deposit, caused by the large proportion of fragments of Permian rocks included in it.

The cuttings northward, at least as far as Armathwaite, are much of the same character as those just described (figs. 14 & 15). It is clear from an examination of them, that the proportion of waterworn materials steadily increases as we advance towards the Solway. Even the clays seem to pass into a loamy deposit, throughout which stones are scattered as they are in the clays; and the general impression left, after examining a long series of sections from the foot of Stainmoor very nearly to Carlisle, is, that the thin intercalated sands seen at the head of the valley swell out, the clays become more and more laminated and interbedded with sand and gravel, and ultimately pass into clean sands and gravels through such loamy deposits as occur about Armathwaite. Here and there in the low ground, beds like the till come in, and over- and underlie the sands and gravels in an irregular way; but there is a steady decline in the amount of clay as we go towards the north-west.

Much of this sand and gravel forms mounds which exactly answer the description of the Irish eskers, and, like them, show that the planes of false bedding incline the same way that the slopes of the eskers do. Some of the mounds are heaped up very irregularly, especially in places where, owing to the form of the ground, there must have been conflicting currents; so that here and there occur a few basin-shaped hollows, such as may be met with in mounds of drift of the same character in the Dale district.

Enough has, perhaps, been brought forward to show that there is a general agreement in the way in which the drifts come on in the Eden valley and the Dale district. In each case the lower till is mostly to be found in the bottoms of the valleys, not far removed from the head of the drainage-area; and the higher till is more angular, and contains, as a rule, less clay and fewer scratched stones than that below.

In each district the deposits of sand and gravel begin to come on in force at the points where the principal rivers of the area deliver a like volume of water; and from these points outward towards the mouths of the rivers, the total quantity of clay in the whole accumulation of drift steadily decreases until very little else than clean sand and gravel is to be found, except in the maritime districts, where the true boulder-clay comes on.

Each district affords proof that the clayey drumlins of the higher parts of the valleys pass into and form parts of the same series with the hummocky mounds and eskers of sand and gravel lower down, in such a way as to lead to the belief that they must have had a common origin.

Intercalated beds of sand and gravel and sheets of gutta-percha clays with curved lamination occur in the till of both districts; and all the evidence points to the conclusion that these intercalated beds have only undergone slight local derangement—and that it is the rule rather than the exception to find them quite undisturbed, except where the disturbance may be satisfactorily accounted for by the dropping of heavy masses of gravel, large boulders, or lumps of ice, or else by the settling-down of the ice-sheet upon the soft beds beneath.

The drumlins that include these intercalated beds of sand and gravel in the Dale district might possibly be accounted for as the moraines of the later glaciers of the ice-period; and therefore, in discussing the origin of these beds, it will be well to confine our attention to those drumlins at the foot of Stainmoor that, from their position, cannot by any possibility have had a morainic origin, but are, in all but the extraneous nature of the included stones, the exact counterparts of the Dale-district mounds, to which reference has been made.

The nature of the beds of till seen in Brough-Castle scar puts the marine origin of any one of them entirely out of the question. As at least seven or eight such beds occur interstratified with sand and gravel, it will be taken for granted that the intercalated beds also are not the result of marine action, but that the whole series is in some way the result of some other and frequently recurring cause. The stiff clay full of blunted and scratched stones of all sizes up to 4 feet, disposed without any regard to form or size, cannot be any thing else than the work of ice: but when we try to explain the presence of seven or eight, or, in some cases, as many as eleven such beds of till interstratified with undisturbed beds of sand and finely laminated clays by the *moraine-profonde* theory, as it is usually (and so far as the writer can gather from the latest books treating

of the subject) universally understood, we meet with complete failure.

It does very well in cases where we have only to account for the origin of an unstratified mass of stiff clay full of glaciated stones whose longer axes are nearly parallel to the underlying rock-surface. It is at least intelligible how a mass of ice which, at the foot of Stainmoor, was certainly not less than 1200 or 1400 feet in thickness, could cause to accumulate here and there beneath it thin deposits of tough clay and scratched stones which had been scraped along between the ice and the rock-surface for many miles. But if any one nowadays needs to be convinced of the power of such a sheet of ice to crush up and contort any soft beds that lay in its way, let him examine a few sections of alternations of hard and soft beds that have lately been bared of drift, at almost any spot over which the ice had a great thickness; it will then be manifest that these thin soft beds of sand and clay occurring interstratified with the till, could not have escaped violent contortion. They would be much more likely to be kneaded up into the clays until every trace of their existence was lost, if the ice ever advanced a single inch over them.

It was mentioned above, that the far-derived boulders had hitherto been met with only in the upper till, or in deposits that are probably referable to that horizon. Taking it for granted that the ice that transported the Galloway boulders right across England to the North Sea, and exercised enough denuding force to tear up Brockram from the bottom of the valley of the Eden, and afterwards transported it up the slopes of Stainmoor, must, if the *moraine-profonde* theory be entirely true, have had a much greater thickness than the ice that was only capable of dragging its *moraine profonde* a few miles; it follows that it must have tended, more than the hypothetical older ice-sheets, to crush and contort every thing that could be thus acted upon from the surface. How then can we account for the presence of entirely undisturbed beds of finely stratified and incoherent sands, and sheets of laminated clays in and beneath the upper till?

As the *moraine-profonde* theory fails to meet the requirements of these cases, it is obvious that some other explanation, which shall be more in accordance with the observed facts, must be looked for.

The writer therefore ventures to lay before the Society a theory that has suggested itself after a long consideration of Prof. Ramsay's theory of Glacial currents, and a careful examination of a considerable tract of country in the north-west of England by the light of this theory.

Most persons who have lately written on glacial subjects have remarked how suddenly the great ice-period was brought to a close. So little modification have the striæ undergone at almost all elevations, that it is no uncommon thing to find the striæ going right across the bed of a considerable valley in such a way as to show that, had the ice dwindled away by slow degrees, and passed back through all the stages of glacier-development to the tiny glaciers of

the later period, all traces of the former existence of the great ice-sheet must have been obliterated from the low ground. Everywhere the ice appears as if, after it had reached its maximum thickness, it had quietly melted away, without the lower part, at any stage of its liquefaction, ever again advancing over the rock.

Another point that many recent authors seem agreed upon, but that is not so well borne out by the facts observed in the district treated of in this paper, is that the till is largely, perhaps almost entirely, made up of detritus scraped from the rocky bed over which the ice was passing—that the till was brought into existence underneath the ice, and there it was kept until the ice melted.

Prof. Ramsay's theory of Glacial currents enables us to go a step further than this in treating of the origin of drift deposits.

We can see that one of the results of such crossing currents would be that streams of ice from subsidiary valleys would frequently keep the level at which they blended with the main stream for some distance from the valley wherein the lesser stream originated, and that, in the numerous cases in which the upper parts of the ice filling a valley were crossing it at various angles according to local circumstances, much of the débris from the lee side of the valley would be swept into the traversed current and transported to the main stream, where these lateral moraines would be intermingled with others derived in a similar way from rocks afar off. What was there to cause the bottom layers, or, indeed, any part of a tributary ice-stream, to pass at once into the lowest part of the main stream, which in no small number of cases must have been flowing in quite a different direction from that of its feeder? Take the case, for instance, of the local ice coming from the Cross-Fell district to join the Eden-valley stream. The directions taken by the main stream and its affluents must have often approached a right angle; and the level at which the local ice blended with the larger stream must often have been several hundred, or even, in some cases, a thousand feet above the bottom of the Eden-valley ice. The behaviour of no modern glacier would warrant us in concluding that, in this and the innumerable similar cases that might be cited, the high-level ice, with its load of boulders, would at once, or at all, work down to the bottom of the main stream.

It would be easy to point to many similar cases where the direction of the higher glaciation was often at considerable angles with that of the adjoining lower ice over which it would pass.

In this way it is quite possible that boulders might be transported across wide valleys without ever reaching the bottom of the ice there, so that the transport of Shap-granite boulders is not difficult to understand when the existence of a great uptravelling mass of ice is clearly proved.

The frequent deflections of each stratum caused by the inflowing of large feeders and the varying form of the rocky bed and the sides of the valley along which the ice was passing, must have contributed in a great degree to that intermingling of boulders derived from widely parted sources that is one of the most noticeable phenomena

in any section of far-derived drift. There seems, too, to be some reason for thinking that this intermingling would be still further brought about by the occasional upforcing of some of the strata of the ice-sheet in places where, so to speak, the ice was closely hemmed in on all sides, as it must have been at the foot of Stainmoor.

When the great ice-sheet began to melt, the stones that were nearest the bottom of the ice, and which, from their position, must have undergone the greatest amount of glaciation, began to be deposited on the floor of glaciated rock, or on patches of the true *moraine profonde*, where these existed. The water resulting from the melting of the bottom ice would find its way here and there towards the sea along channels in the slowly thickening deposit of till. Where such ridges of rock existed as resulted from the unequal wear of hard and soft beds, the water would be more likely to flow along the intervening hollows than to pass along or across the higher ridges; so that in this way it must often have happened that the deposition of till went on over preexisting rock-ridges, while the intervening hollows were kept clear by the water that flowed in them. It is obvious that the further the point from the head of the valley the greater would be the quantity of water flowing beneath the ice. It should be borne in mind that there would be not only the water resulting from the melting of a great thickness of ice, but the rainfall of the period to be carried off in some way towards the sea. We can therefore understand how it is that the drift-materials that were slowly melting out of the ice sheet, became more and more waterworn in proportion to the distance from the head of the valley. As the currents shifted they must have allowed till to accumulate in parts where previously nothing but sand and gravel had been laid down; while, on the other hand, they must frequently have cut into banks of till, and afterwards filled the denuded hollows with waterworn materials as their course slowly changed. In this way there can be little doubt that the drift in the lower parts of the Eden valley must frequently have been removed soon after deposition, and the materials re-sorted and further waterworn, and afterwards redistributed in some protected spot further down the valley.

Here and there waterworn materials must have found their way down through crevasses to the bottom of the ice, so that nests of undisturbed sand and occasional patches of gravel would accumulate where, for some distance around, nothing but till was being left by the ice. In the quiet spots amongst the till, out of the reach of the subglacial streams, runlets of water charged with fine glacial mud must have flowed over the irregularities of the till, depositing sheet upon sheet of fine clay until some of the inclined sheets of gutta-percha clays were accumulated. It would be very difficult to give any satisfactory explanation of their origin besides the one here advanced. If the clays were deposited under water, they would not fail to be spread out in perfectly horizontal sheets; at any rate it is quite impossible that they could be thrown down at angles of from

15° to 30°, as are many in the Longwathby cuttings and elsewhere. Nor will any other explanation yet given make it clear how these laminated and exceedingly fine clays could be accumulated while big and little stones were being dropped into the soft clays below to such an extent that some of the gutta-percha clays gradually pass into good characteristic till.

It cannot be doubted that fragments of ice would now and then fall into the soft drifts, contorting the beds some little distance around, and that, as Sir Charles Lyell has remarked, the detritus that accumulated around these lumps of ice would be thrown down in great confusion when the ice melted. Add to this the occasional local contortion caused by the falling of large boulders, the heaping up of masses of coarse gravel upon unconsolidated beds of sand and mud, the slipping forward of soft beds deposited on a slope, and the occasional movement of the slowly melting sheet of ice, and we can see that there is no occasion to call in the agency of floating ice to account for any amount of local contortion which the beds may have undergone.

In the maritime districts beyond the edge of the ice it is not at all unlikely that floating ice was at work contorting the beds; but as Mr. Geikie has lately remarked that the importance of floating ice as a boulder-transporting agent has been greatly overestimated in dealing with the British drifts, it is not at all unlikely that what has been set down unhesitatingly as contortion caused by floating ice may, in a few cases, have been in reality due to some of the causes enumerated above.

In the higher parts of the valleys, where the quantity of water flowing beneath the ice was less than elsewhere, there would be little or no denudation or water-wearing of the drift going on; so that in such places the accumulation of till must have gone on almost uninterruptedly until no more ice was left. In this way those sloping banks and plains of till that occur high up near the water-sheds must have been formed.

The boulders in the upper parts of the ice, which in a great many cases must have been those that had travelled furthest, would, as Mr. Geikie has remarked, often be stranded at high levels as the ice melted; but if the theory here put forward be true, this deposition of the highest boulders must in the majority of cases have been the last work of any given part of the ice-sheet; so that while till and gravel were being accumulated at low levels, the deposition of the higher-lying boulders was going on; and it was not until the ice was nearly all melted, and therefore the greater part of the mounds of till and of the eskers was heaped up, that the higher parts of the ice-sheet, with their load of far-travelled and often angular boulders, would be left as traces of the last work of the waning ice-sheet.

It should, however, be mentioned that in the Eden valley and in the Dale district there are no more boulders *on* the Eskers and drumlins than occur in sections of those drifts of the same area; in other words, boulders are quite as common *in* the eskers as they are *on* their outsides.

Before concluding, it will perhaps be well to refer to one or two other glacial phenomena this theory of the origin of drift seems to throw light upon.

In many places in the Dale district, beyond a radius of ten or twelve miles from the principal centre of dispersal of the ice, great heaps and ridges of unstratified drift, with very little clay and almost no scratched stones, but charged throughout with angular blocks, occur here and there on the higher ground. It seems mostly to lie on the lee side of prominent ridges which the ice must have swept over at the time when it attained its greatest thickness. Most of it has a very morainic look, which is rendered still more striking by the irregularly moundy character of its surface. As a rule, the included blocks seem to indicate that the bulk of the drift was derived from the higher-lying rocks of the district, fragments of beds below the upper division of the dale-rocks being seldom met with. Had it not been that these highest beds referred to are largely made up of shales and soft beds of a similar nature, to the extent of fully half the whole bulk of the rocks, the origin of these mounds could have been easily enough accounted for; but the absence of any noticeable proportion of clay or of shale-fragments renders it extremely unlikely that the moundy-surfaced drift represents either the lateral or the terminal moraine of any part of the great ice sheet as it receded up the dales. The detritus scraped off from ridges that the ice was crossing at high levels must very frequently have found its way into the main stream at nearly the same level, and, as a consequence, must very rarely have got low enough to undergo any great amount of glaciation by being forced over other high-lying rocky surfaces that might help to round and scratch any of the blocks imbedded in the ice. All the soft beds that entered the ice along with the harder blocks would soon be either decomposed or crushed into clay, which would sooner find its way to the bottom of the ice than any of the stones that entered with it. A sheet of ice charged in this way must always have had the greatest proportion of worn stones and clay near its base, and the most angular and least clayey detritus at the top. When such a sheet of ice flowed across many valleys, it can hardly be doubted that in the majority of cases it was the upper part only of the ice that would cross the next opposing ridge; and in this way the materials of the till would be sorted out again and again from the angular drift. As the ice melted, it deposited this angular drift in exactly the same way as it did the till at lower levels, the difference being that in the case of this moraine-like drift little or no clay and hardly any scratched stones were imbedded in the ice to be deposited along with the angular drift, while nearly all the clay was left in the till.

The heaping-up of masses of drift at the main-valley end of the dividing ridge between two tributary dales, pointed out in Mr. Dakyns's paper "On the Glacial Phenomena of the Yorkshire Uplands"* is to be accounted for in the same way as the shaping of the drumlins. The water resulting from the melting of the ice must

* Quart. Journ. Geol. Soc. vol. xxviii. (1872) p. 384.

have flowed very nearly along the present course of the stream at the bottom of the valley; so that the deposition of drift over the ridge intervening between the two dales went on in many cases uninterruptedly from the first melting of the ice until it was all gone, while at lower levels the stream would be continually transporting the drift-materials towards the end of the dale as fast as they melted out of the ice.

There is one more point to which it will be well to call attention, although it relates to a district far from that which is here treated of. There has been some difficulty in accounting for the absence of much drift on the eastern slopes of the Pennine chain at some distance to the south of the Dale district. May not this be due to the fact that on the eastern side of England there was no great centre of ice-dispersal in the relative position of the Lake district, the general form of which caused the Dale-district ice to be pressed close up to the western side of the Pennine chain? It is far from unlikely that the crescentic group of high fells ranging from High Seat to the south of Conistone Old Man caused a south-easterly current to flow at a high level over the low ground between Kendal and Kirkby Lonsdale. Such a current could hardly have been without its influence upon the course taken by the upper parts of the Dale-district ice, and it must have helped very materially to keep them pressed against the western side of the Pennine chain. On the eastern side there is no evidence of any such current; and the ice there, instead of flowing close to the high ground as it did on the west, seems to have gone away steadily in a south-easterly direction towards the North Sea.

Conclusion.

The principal conclusions, therefore, which have been drawn from the facts detailed in the foregoing pages are the following:—

The whole of the district treated of in the paper was once enveloped in a part of the great ice sheet whose existence in adjoining districts has been demonstrated by Messrs. Tiddeman and Ward.

There seems evidence to prove that the upper limit of this part of the ice sheet stood somewhere between 2200 and 2400 feet above the present sea-level, at the points where the ice sheet attained its greatest thickness.

A line of ice sheet extended nearly along the present watershed of the Lake district to the highest ground in the Yorkshire dales. To the south of this line the ice at high levels flowed straight away over the fells into Lancashire and West Yorkshire; while that to the north, after flowing a short distance into the Eden valley, was turned to the east, and compelled to flow over Stainmoor towards the North Sea.

Some evidence has been given to prove that few even of the smaller valleys could have been the work of ice, but that, on the contrary, the ice seems to have tended rather to level the minor inequalities of the surface, and thus to efface the smaller valleys.

It has also been shown that much of the surface-configuration that is characteristic of the Dale district has been due to glacial erosion—and that, as a perfect gradation in form may be traced from the straight lines of scar, which it seems impossible to refer to any other than glacial origin, to the crescentic scars that have all the characteristics of cirques, these also have originated through glacial erosion.

In treating of the origin of drift, the principal conclusions are, that the facts observed are irreconcilable with either the *moraine-profonde* or the marine theory—and that the angular moraine-like drift occasionally found in parts of the dales, the upper and lower tills and the intercalated beds, the deposits of sand and gravel that form the eskers, and, finally, the numerous boulders that are left at nearly all elevations are each and all the results of the melting of a great sheet of land ice that was charged throughout with rock-fragments of all sizes and of all the kinds occurring within the area wherein the ice originated.

Lastly, the present unmodified form of the drumlins and eskers, the entire absence of any thing like a terrace of marine origin, and the difficulty of pointing to any case of boulder-dispersal in directions that glacial currents may not have taken—all seem to prove that, whatever submergence followed the climax of the glacial period, most of the existing glacial phenomena are the work only of the ice sheet. So little, indeed, has the aspect of the country changed in Postglacial times that in many places the larger rivers are even now above the bases of the adjoining drift-mounds, whose present form can hardly be referred to any other than glacial action; and Postglacial denudation generally has effected so little that by far the greater part of the present surface-configuration has, in one way or another, resulted from the former presence of the great ice sheet.

EXPLANATION OF PLATE II.

Map to illustrate the Glacial Phenomena of the Eden Valley and Yorkshire-dale district.

