22. *The GLACIATION of the BLACK COMBE DISTRICT (CUMBERLAND).*

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[PLATES XLI-XLIII.]

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I. INTRODUCTION.

BLACK COMBE—a long whale-backed ridge of slate rising to a height of 1969 feet—is situated a few miles south of the mouth of Eskdale, and dominates the southward-trending extremity of Cumberland, which is separated from Lancashire by the Duddon valley and estuary. The coast-line of Cumberland, from St. Bees Head to Furness, is in the same latitude, and occupies a somewhat similar position—with the exception of its trend—, as the Cleveland shoulder of Yorkshire.

While working upon the solid formations of this area four or five years ago, my attention was diverted to the study of the superficial deposits, dry rock-valleys, and other signs of glacial activity, which presented many problems of great interest. The relations, for example, between the Lake-District Ice and the Irish-Sea Ice are well exhibited, and many of the glacial phenomena of the Isle of Man are here repeated.

My thanks are due to Mr. Herbert H. Thomas, Dr. J. E. Marr, Mr. G. Barrow, and Mr. G. W. Lamplugh for valuable suggestions and encouragement; also to Mr. E. L. Guilford, who accompanied me in the field, and placed many of his photographs at my disposal.

Between 1869 and 1878 several valuable papers¹ dealing with the drifts of North-West Lancashire and parts of Cumberland were contributed by D. Mackintosh to the Geological Society and the 'Geological Magazine.' Most of his remarks on the Black Combe district are confined to the distribution of the granitic drift, but he also describes a traverse through the Whicham Valley and one ascent of Black Combe. In general, he infers that the drifts were deposited by the sea and floating ice, though more or less of the clay and loam composing them may have originated as subglacial mud.

C. E. De Rance,² while believing more thoroughly in the land-ice glaciation, thought that the lower parts of the Lake District were at first under water, and that the Middle Drift Sand required a subsidence of 1400 feet for its formation. The Upper Boulder Clay he considered to be due to ice-foot. On re-emergence of the land, valley-glaciers once more appeared. He makes no particular reference to the Black Combe area.

Clifton Ward,³ in his paper on 'The Glaciation of the Southern Part of the Lake District,' showed that huge glaciers passed down Eskdale, Wastdale, the head of Duddondale, and southwards over Conistoun; but he carried his observations no farther west or south. He postulated a later submergence of 2000 to 3000 feet, but allowed a re-elevation of the land for a late set of glaciers.

A manuscript report (*circa* 1877, preserved in the Office of H.M. Geological Survey) by W. T. Aveline, C. E. De Rance, and Hebert, on Sheets 98 N.W. and 99 N.E. (O.S.), throws a certain amount of light on the distribution of the glacial deposits in the St. Bees, Scafell, and Conistoun directions.

In a paper on 'Boulder Clay,' published in the 'Transactions of the Cumberland Association' for 1877-78 (pt. iii, pp. 91-108), C. Smith discusses the origin of the Cumberland drifts.

Two papers⁴ by Mr. J. D. Kendall, on the boulders and glacial deposits of West Cumberland, were published shortly afterwards. Like Mackintosh (to whose work he makes no reference), he attri-

¹ 1. 'On the Correlation, Nature, & Origin of the Drifts of North-West Lancashire & Part of Cumberland, with Remarks on Denudation' Q. J. G. S. vol. xxv (1869) pp. 407-31; 2. 'On the Dispersion of Criffell Granite & Caldbeck Porphyry over the Plain of Cumberland' Geol. Mag. vol. vii (1870) pp. 564-68; 3. 'On the Drifts of the West & South Borders of the Lake District, & on the Three Great Granitic Dispersions' *Ibid.* vol. viii (1871) pp. 250-56, 303-12; 4. 'Observations on the More Remarkable Boulders of the North-West of England & the Welsh Borders' Q. J. G. S. vol. xxix (1873) pp. 351-59; 5. 'On the Traces of a Great Ice-Sheet in the Southern Part of the Lake District & in North Wales' *Ibid.* vol. xxx (1874) pp. 174-79; 6. 'Results of a Systematic Survey, in 1878, of the Directions & Limits of Dispersion, Mode of Occurrence, & Relation to Drift-Deposits of the Erratic Blocks or Boulders of the West of England & East of Wales, including a Revision of many years' Previous Observations' *Ibid.* vol. xxxv (1879) pp. 425-53.

² 'On the Two Glaciations of the Lake District' Geol. Mag. vol. viii (1871) p. 116.

³ Q. J. G. S. vol. xxxi (1875) pp. 152-65.

⁴ 'Distribution of Boulders in West Cumberland' Trans. Cumb. Assoc. pt. v (1879-80) pp. 151-57, and 'The Glacial Deposits of West Cumberland' *Ibid.* pt. vii (1881-82) pp. 61-78.

Fig. 1.—*Geological map of the Black Combe district, based on the 1-inch Survey Map. (Scale: 1 inch=2 miles, or 1:126,720.)*

buted the distribution of Scottish rocks to boulder-bearing icebergs swept along by marine currents. He also required two separate submergences of the land to account for his facts, although he recognized the active part played by land glaciers in the formation of the boulder-clays.

Among the writings of T. Mellard Reade, that upon the Eskdale Drift and its bearing upon glacial geology,¹ published in 1893, is of great interest in its relation to the subjects discussed below. In a later (1896) Address² he deals with the Low-Level Marine Boulder Clays and Sands between St. Bees Head and Ravenglass.

Since that time little seems to have been written about the Black Combe area, although Mr. G. W. Lamplugh drew a comparison between the drift-plain west of Black Combe and the northern drift-plain of the Isle of Man.³

II. GEOLOGICAL STRUCTURE.

The district examined may be divided in a broad way into three main physiographical divisions, from east to west, as follows:— (1) The Duddon Valley and Estuary, (2) the mountainous tract between the Duddon Valley and the plain, (3) the low plain at the foot of the mountains, and bordering the sea between Millom and Ravenglass.

In the greater part of the Duddon Valley, and over the mountain tract, the glacial drifts have merely modified the pre-existing topography, but the third district—the plain—is almost entirely composed of drift deposits of considerable thickness, which descend below sea-level beneath a large part of the plain's surface extent.

Near Kirsanton and Millom in the south, some low ground is occupied by Carboniferous Limestone. North of Silecroft the formations beneath the plain are considered to be of Triassic age; but, with the exception of one exposure mapped by Aveline near Corney Hall, north of Bootle, there is no visible outcrop of these rocks.

The mountain country consists chiefly of three distinct types of rock: namely, slate, volcanic rocks, and granite. An inlier of so-called 'Skiddaw Slate,' roughly triangular in shape, and 12 or more square miles in extent, forms a group of fells reaching a height of 1969 feet at Black-Combe summit. The bulk of this mountain consists of blue-grey slates of felspathic appearance, tremendously compressed and very highly cleaved, the cleavage-planes dipping generally in a north-westerly direction. In some cases secondary cleavage and pressure has resulted in the production of slates with frilled surfaces and presenting a glossy appearance. Chevron folds and belts of rock riddled with vein-quartz, which coincide roughly with the direction of cleavage, testify also to the tremendous pressure brought to bear upon these rocks.

¹ *Geol. Mag.* dec. 3, vol. x (1893) pp. 9-20.

² 'The Present Aspects of Glacial Geology' *Proc. Liverp. Geol. Soc.* vol. viii (1897-1900) pp. 13-31.

³ 'The Geology of the Isle of Man' *Mem. Geol. Surv.* 1903, p. 366.

Some of the slates are banded. In such cases it can be shown that the directions of true dip and cleavage-dip are, as a rule, non-coincident and sometimes entirely opposed one to the other.

The age of these rocks, the nearest equivalents of which are, perhaps, the pale Manx (Barrule) slates, is at present unknown. The slates on the south-eastern side of the tract, which form the floor of the Whicham Valley and the lower slopes on both sides, are of a different type, and should, before long, yield definite palæontological evidence as to their age. They appear to be separated from the pale slates on the west by a plane (perhaps a thrust) which dips in a north-westerly direction at about 15° . They are soft blue shales, ash-looking slates, fine black mudstones, and grits. Near Whicham Mill Ford I have found *Caryocaris wrightii* and an obscure fragment of a graptolite¹ at the quarry west of the mill.

South-east of the mill the cleavage is disturbed by faults crossing the valley in a north-easterly direction, and on the south side of the valley both dip and cleavage are frequently reversed.

Upon the north, east, and south-east the slates are bounded by rocks of the Borrowdale Series, from which they are separated either by faults or by thrust-planes. The rocks are chiefly andesitic (and sometimes vesicular) lavas and ashes, many of the latter being coarsely banded. On the north, a well-recognized type is a porphyritic andesite occurring, with associated ashes and vesicular lavas, between Bootle and Stoneside Hill. On the north-east are the andesite and ashes of Mere Crag, and the banded ashes of Lath Rigg, some of which contain fragments of rhyolite; and on the southern slope of Wrayslack Hill, about half a mile east of Knott Hill, occurs a coarse breccia, with blocks of spherulitic rhyolite measuring up to 2 feet in length.

Cleaved and banded ashes also occur between Millom and The Green.

In addition to the above, there are numerous small intrusions in both Borrowdale rocks and Skiddaw Slates.

The volcanic rocks are flanked on the south-east, near Millom, by rocks of the Coniston Limestone Series and Carboniferous Limestone.

About 2 miles north of Black Combe summit the southern part of the Eskdale Granite is in contact with a narrow strip of volcanic rocks averaging only half a mile in width. The northern margin of the Skiddaw Slates is, indeed, within the metamorphic aureole of the granite, which makes it difficult to determine accurately the position and character of the junction between slates and volcanic rocks. The granite averages 2 miles in width as far north as the mouth of Eskdale, after which its outcrop expands considerably. Its eastern boundary forms fairly high ground, but on the west there is a descent to a low plateau dissected by the marginal drainage of the ice-sheet.

¹ Harkness records *Graptolites sagittarius* from the debris of quarries in the southern escarpments of the mountain; see 'On the Skiddaw Slate Series' Q. J. G. S. vol. xix (1863) pp. 131, 132.

III. PRE-GLACIAL CONDITION OF THE DISTRICT.

With the exception of the drift plain, the main features of the district had been developed before the advent of the Ice Age. As a result of the glaciation, some of these features were accentuated, others were subdued, and some new ones were introduced.

The cleavage-dip of the slate accounts in part for the smooth northward-facing slopes of Black Combe, and the more craggy south-eastern and south-western slopes. These features, however, were certainly accentuated by glaciation. Over-steepening of the seaward slope of the mountain accounts for the precipitous descents upon that side. The sides of the Whicham Valley are similarly affected, and the valley-bottom has been somewhat over-deepened. In the volcanic tracts the rugged features, which now appear to be so prominent when one is looking in a direction opposed to that of the ice-movement, would, in pre-Glacial times, have been prevalent everywhere. The chief alterations in feature of the granite tract would consist in the destruction of 'tors' and the removal of a great quantity of rotten rock from the lower ground. Some of the drift-deposits of the plain descend below sea-level: hence it is quite possible that the pre-Glacial sea may have touched the foot of Black Combe; but, even if this were the case, it would not account for the smoothed and oversteepened slopes, cut-away spurs, and hanging valleys which occur at higher elevations.

In the mountain districts the main pre-Glacial drainage-lines were similar to what they are to-day. Upon the advance of the ice some of the smaller channels were choked with drift; but in most of these the post-Glacial streams follow the old lines, and are removing the extraneous material from their valleys.

IV. THE MAXIMUM GLACIATION.

Evidence as to the direction of movement of the streams of ice which invaded the district during the maximum¹ glaciation is furnished chiefly by (a) the composition and distribution of the drifts, (b) the erratics, and (c) the grooved, smoothed, and moutonné surfaces, seen to perfection in the volcanic tract. Minor evidence is yielded by striæ and by scoured or steepened valley-sides, cut-away spurs, and hanging valleys, and, during the stages of retreat, by the trend of moraines and of marginal drainage-channels.

My observations tend to show that, during the flood-tide of glaciation, the whole district was completely overridden by an ice-sheet formed by the confluence of the edge of the Lake-District ice-cap with the great Irish-Sea Glacier, one of the points of contact between the two lying about a mile west of Black-Combe summit.

¹ The anomalous distribution of some of the Lake-District boulders may have been due to valley-glaciers reaching the sea before its invasion by the Scottish ice, and launching bergs which scattered in various directions and strewed rock-fragments over the sea-bed.

The top of Black Combe (1969 feet) was overridden by comparatively clean ice, which ascended the gentle northern slopes, signs of its passage being furnished by a few scattered boulders near the Cairn. There is plenty of evidence of the ice-movement over the lower shoulders of the mountain.

V. (1) THE LAKE-DISTRICT ICE.

The Lake-District ice moved from three main directions: (i) the Broughton Valley; (ii) the Duddon Valley and the high ground on the west; and (iii) Eskdale.

(i) The Broughton Valley.—W. T. Aveline¹ states that in the first of these districts the Broughton drift chiefly consists of scattered angular or partly waterworn stones, and large ‘perched blocks.’ In places it has filled up some of the deep valleys, which generally have been again excavated by the existing streams, showing a rocky bottom. Where the drift assumes any thickness, as on the side of some of the valleys, it is found to consist of travelled stones or boulders scattered in a finer matrix derived from the disintegration of the surrounding rocks. He records huge erratics of volcanic breccia on Broughton Moor, and one (the ‘Red Gall Stone’) on Tower High Common, but none of them seem to have travelled far. Some huge boulders of Coniston Limestone on Broughton Moor, and the fragments of dark graptolitic mudstones in the drift near the Coniston Copper Mines, have apparently come from the north-east.

(ii) The Duddon Valley and the high ground on the west.—The Duddon Valley, cut entirely in volcanic rocks, is beautifully glaciated. On looking up the valley we see the craggy faces of the cliffs and rocky knobs; but, on looking down, we notice that the smoothed backs of the knobs, partly covered by grass and with their bases often plastered about with boulder-clay, give to the scene a remarkably smooth and tame appearance.

In the lower part of the valley, between Ulpha and the Duddon Bridge, are splendid examples of *roches moutonnées*. The ice-movement was here from north 30° east.

Of the upper part of the valley Mackintosh² writes:—

‘The eastern slope . . . of the Duddon is covered with a succession of gently-swelling knolls (with rocky nuclei) of pinel, and overlying loam, both containing large boulders. In many places there are *roches moutonnées*, with parallel undulations or wide ~-shaped grooves (as well as minute striæ) pointing north-north-east, or nearly in the direction of the valley.’

Thus the general direction of ice-movement between the Broughton-Coniston and Duddon Valleys was south-westward from the direction of the Coniston Fells, crossing the Duddon Valley between Ulpha and Duddon Bridge obliquely. West of this part of the valley ice-moulded surfaces, occasional striæ, and rock-grooves,

¹ MS. report.

² Geol. Mag. vol. viii (1871) p. 306.

on the highest ground, prove that the direction of flow was maintained for about a mile, after which it turned southwards owing to pressure of ice moving in that direction. The hill-slope, between the 400- and 700-foot contours, north-west of Duddon Bridge, consists of a series of scarps which have been polished and striated so that the hillside is now practically one gigantic *roche moutonnée*, the movement having been obliquely upwards.

Trails of boulders descend the eastern slope of the Black Beck Valley about 2 miles north of The Green, and in some cases cross to the other side. A boulder of the coarse rhyolitic breccia which occurs *in situ* at 600 feet was found half a mile away, on the west side of the valley, below the 500-foot contour, the direction of transport being in direct alignment with the striation on the parent rock.

The Coniston-Broughton ice crossed the Duddon Estuary, over-rode the high ground near Lady Hall, and choked the Black Beck Valley near The Green with several large drumlins.

From Duddon Bridge to Lady Hall the lower slopes on the west of the estuary have been over-steepened and all spurs cut away. On the higher ground the rock is scored by glacial grooves, and many perched blocks, ranging up to 12 feet or more in greatest diameter, are scattered about. A boulder of banded ash, measuring $8 \times 6 \times 5$ feet, resting on a smoothed surface of cleaved ash, occurs by the roadside a few yards north-west of Haws near The Green.

South of The Green, glacial grooves and splendid *roches moutonnées* clearly indicate that the direction of movement of the higher parts of the Duddon ice was south-westward, until contact with the Whicham-Valley ice caused it to take a more southerly course along the eastern slope of Millom Park. Farther south it was affected by the Irish-Sea ice.

Boulder-clay is frequently exposed at low levels between Duddon Bridge and Lady Hall: it also occupies the hollows on the higher ground to the west, and is plastered round the smoothed rock-surfaces.

About 400 yards south of the Inn, at The Green, is a 20-foot (artificial) section in one of the above-mentioned drumlins. The deposit consists of a more or less homogeneous brown clay or loam, sometimes slightly reddish, and contains streaks of reddish-brown sand or fine gravel, which dip gently in both directions along the line of section, that is, transverse to the long direction of the drumlin. The larger boulders are 3 or 4 feet long, and consist chiefly of Borrowdale lavas and ashes or pinkish quartz-porphyrries. Some of the smaller boulders of sedimentary rock, such as greenish-blue shales, micaceous slates, and micaceous banded grits, are frequently striated. These rocks, and a few small boulders of rotten Coniston Limestone, suggest the Coniston-Broughton district as their seat of origin.

A second pit in the same drumlin shows a similar section of brown, slightly loamy clay—a true till—overlain by tawny sand with boulders on the hill-slope. Boulders of Coniston Limestone were

also found in a gravel-pit north-west of Hallthwaite Church, and on Millom Park.

At the flood-tide of glaciation the Whicham Valley was filled chiefly by ice moving southwards from the high ground west of the Duddon. Some of this ice overrode the northern slopes of Black Combe, and helped to fill the valleys tributary to the Whicham Valley. Between Ulpha Park, Thwaites Fell, and Prior Park, about the head of Black Beck, a large tract of undulating ground, rising over 1000 feet, is covered by reddish-brown boulder-clay derived almost entirely from volcanic rocks, upon which it also lies.

Craggy ground on the north-east side of Black Beck, opposite Swinside Fell, furnishes proof, in its moulded surfaces, of the southward movement of the ice. Boulder-clay is plastered on the northern slopes of Knott Hill, which split the ice-stream until it was swamped beneath it. Just below the 900-foot contour the eastern face of the hill is beautifully smoothed, while trails of boulders are directed in a southerly direction along the southern slopes. The line of confluence between this ice and that from the Duddon Valley is marked by a boulder-covered ridge, about half a mile long, which terminates east of Baystone Reservoir.

In the western half of Millom Park the southerly direction was maintained, and slate-débris was dragged up on to the volcanic rocks above Sandholes Wood. A boulder of ash, measuring 15×8 feet, lies near the same spot; but over the whole of the above-mentioned area the most conspicuous, though not necessarily prevalent, type of boulder is a reddish quartz-porphry, similar to those which occur (among other places) *in situ* near Seathwaite, in the Duddon Valley.

Ice pressed through the gap (300 to 400 feet above O.D.) between Millom Park and Lowscales Bank, filling the hollow south of the latter with boulder-clay containing well-glaciated fragments of Skiddaw Slate. On Pohouse Bank a boulder of banded ash, measuring $11 \times 8\frac{1}{2} \times 6\frac{1}{2}$ feet, which rests at 550 feet, may have been quarried from a lower position on Lowscales Bank, but its glaciated appearance suggests that it came from a greater distance. Moutonné surfaces show that the Whicham-Valley ice was there, turning to the south-east in obedience to the thrust of the Irish-Sea ice, which pressed into the mouth of the valley. Boulder-clay is chiefly confined to the lower parts of the valley and to the gentler slopes upon its sides; it is said to be very thick at Baystone Reservoir.

There are three well-marked valleys opening on the Whicham Valley north-east of Black Combe summit. Ice crossed the watershed in a south-easterly direction into the first of these—that of Whicham Beck, the northern side of which is still filled with drift.

In the valley of Stoupdale Beck a number of boulders of pale quartz-porphry and of Stoneside Andesite (p. 406) occur at 1250 feet immediately south of Stoupdale Crag. The andesites have been carried directly over the watershed from their position *in situ*.

Below the falls, about a third of a mile down stream, the cliff on the

south-east side of a southward-entering tributary has been polished by ice moving in a south-easterly direction. A similar example occurs about 400 yards from the head of Whicham Beck.

During the maximum glaciation the ice apparently filled Whitecombe and its tributary, Blackcombe Valley. The watershed at Whitecombe Head (1429 feet) is covered with peat, but the passage of ice over it is revealed by the presence of a few small boulders of quartz-porphry and volcanic rocks in slaty rubble beneath the peat. Near the head of the combe the ice appears to have overridden a mass of weathered and unstriated slate, in which the stream has now cut a gorge. Farther down, a true slaty boulder-clay with striated stones sets in, and in the lower parts of the valley becomes almost continuous with that spread over the floor of Blackcombe.¹ A few yards below Whicham Mill Ford the slate is turned over to the south by the downstream ice-movement.

North of Black Combe a few boulders of Eskdale Granite lie upon the drift-covered slopes south of the Fell road from Bootle to Broughton, and about 550 yards south-east of the eastern boundary of the granite. Stoneside Hill and the ground more than half a mile to the west of it, south of the granite outcrop, are free from drift, the only erratics noted being volcanics. Moutonné surfaces on Stoneside Hill point to an ice-movement slightly east of south; but the chief streams of boulders from the granite passed to the north-west of the hill in the direction of Bootle Fell, where they occur in considerable numbers.

On the gentle slope north of Black-Combe summit there are a few scattered boulders of coarse ash, and of pale quartz-porphry with white mica, like that of the dykes exposed in Grainsgill Beck (between the 1000-foot and 1250-foot levels) about a mile to the north. Their occurrence seems to prove that the mountain-top was buried beneath ice laden with very little débris.

(iii) Eskdale.—It is important to decide how much of the ice moving along the coast should be considered as Irish-Sea ice, and how much as of local origin. When a tributary glacier has added its quota to the edge of a main glacier, it may for a time retain its individuality as a distinct stream, yet it eventually becomes incorporated in the main stream and takes its name. So, in this case, ice-streams descending from Eskdale, and the valleys of the Mite, Bleng, Irt, Esk, and Ehen, farther north, added their share to the fringe of the Irish-Sea ice-sheet and travelled down the coast alongside it and one another, each for some time preserving its identity. After travelling a few miles, however, these streams, and the different types of drift carried along by them, to a great extent intermingled. The edge of the ice was also crowded inland, and so the drift from one formation was moved inland across other formations to the east. It seems well, therefore, to regard the local additions to the Irish-Sea ice as part of that body.

¹ This was possibly the result of later cirque-glaciation.

(2) THE IRISH-SEA ICE.

In the neighbourhood of Bootle the Ennerdale ice had become to all intents a part of the Irish-Sea ice, while the Eskdale ice still maintained its identity in some degree, yet by the time Whitbeck was reached it, in turn, was almost inseparable from the Irish-Sea ice. After passing Whitbeck the edge of the ice was forced first into the mouth of the Whicham Valley near Silcroft, diverting the flow of the ice down that valley, as above explained (p. 410), and then some distance up the broad estuary of the Duddon, where it also affected the flow of the local ice. Having incorporated the Whicham-Valley and Duddon ice it passed across parts of Furness and Morecambe Bay, and impinged upon the Fleetwood and Blackpool coastline.

The evidence for these movements will be found below in the description of the drifts left by the Irish-Sea ice, which it is now proposed to set forth in some detail, and at the risk of subsequent repetition.

VI. THE DRIFT-DEPOSITS OF THE PLAIN AND THE ADJACENT HILL-SLOPES.

In describing the drifts of the plain¹ between St. Bees and the Duddon, Mackintosh recognized three divisions in upward succession :—

- (a) A Lower reddish, yellowish, or yellowish-brown Boulder Clay or 'pinel,' often varied by a light bluish or greenish tint, and containing the greatest number of large boulders. This, he considers, was mainly derived from the waste of the volcanic rocks and Coal-Measure shales of Cumberland.
- (b) The sand and gravel formation of the plain, containing pebbles and a few boulders of most of the rocks found in the clay above and below it.
- (c) An Upper red loamy clay (partly derived from the waste of Permian [Triassic] strata), containing few boulders.

In his discussion of the general results of his studies²—embodied in eight papers—he considers that the rounded, smoothed, and polished boulders must have been chiefly shaped by floating ice and sea-waves. He infers that floating or ground-ice glaciated a great part of the Lake District; that the drifts were deposited by the sea and floating ice; that more or less of the clay and loam comprising them may have originated as subglacial mud; that the Middle Sand and Gravel were accumulated during the gradual rise, and not during the fall of the land, as C. E. De Rance believed; and that the Upper Boulder Clay of the plains was deposited during a succeeding submergence, the vertical extent of which was at the very least 1300 feet.

¹ 'On the Dispersion of Criffell Granite & Caldbeck Porphyry over the Plain of Cumberland' *Geol. Mag.* vol. vii (1870) pp. 567–68.

² 'On the Drifts of the West & South Borders of the Lake District, & on the Three Great Granitic Dispersions' *Geol. Mag.* vol. viii (1871) pp. 310–12.

The section¹ which he drew of the drifts between Black Combe and the sea gives a fairly correct impression of their general relations; but these general relations seem to be best explained on the assumption that the drifts are all the product of an ice-sheet which was resting upon the shelving shore of the Irish Sea Basin.

(i) Thickness of the drifts.—There seems to be, on the whole, little available evidence as to the thickness of the drifts near the sea-border, yet the records obtained show that, in general, they descend far below sea-level. At Thornflat, Drigg, about 50 feet above sea-level, a boring passed through 160 feet of Boulder Clay, with seams of running sand, without reaching its base; but near Bootle, Aveline mapped sandstone *in situ* (p. 405) at nearly 150 feet above sea-level. In many places between Bootle and Silecroft it seems likely that the inland drifts may descend below sea-level, as they do in the coast-sections. If this be so, the sea, in pre-Glacial times, assuming the present level to be the same, may have washed the western slope of Black Combe, forming a sea-cliff now concealed.

A boring, recorded by Mackintosh,² at the south-western end of the Whicham Valley, was stopped in 300 feet of sand, but we are not informed whether this sand is Glacial or not; the lower part of the boring may well have been in Trias. I have been informed that many borings through the alluvium, close to and east of, Silecroft, in search of hæmatite, have failed, sand only being encountered. Off Hodbarrow Point,³ south-east of Millom, a boring proved 132 feet of clay, and others, farther in the estuary, passed through a great thickness of sand (? estuarine), sometimes resting on clay. Near Burnfield, about a mile and a quarter north of Millom, gravel extends to 70 feet below sea-level, when slate is encountered.

East of the Duddon, at Irleth, near Askham in Furness, the total thickness of the three drifts was 291 feet, resting upon limestone some distance below sea-level.

(ii) St. Bees Head to Hycemoor.—Aveline says of the St. Bees Sandstone area:—

‘Much of the ground under which the sandstone lies is covered with superficial matter, this matter being foreign-derived stones and boulders mixed up with sand and fragments disintegrated from the red sandstone itself. In many cases it may be said to be buried in its own waste. In many quarries the breaking up of the higher beds may be observed.’ (MS. Report.)

Hebert states⁴ that on the sandstone there are large tracts of

¹ ‘On the Drifts of the West & South Borders of the Lake District, and on the Three Great Granitic Dispersions’ *Geol. Mag.* vol. viii (1871) p. 255.

² *Q. J. G. S.* vol. xxv (1869) p. 428.

³ Geological Survey 6-inch map.

⁴ MS. Report.

peaty land—probably not filled-in tarns, but due to growth of peat on swampy land formed on the sandy drift covering the sandstone.

On Cleator Moor¹ reddish-brown Boulder Clay, with boulders chiefly of Ennerdale Syenite and trap, rested on a striated surface of Carboniferous Limestone, the striae being between north-east and north-north-east. The sandstone of St. Bees Head also is finely striated at 300 feet from north 30° east.² Between St. Bees and Gosforth there is a succession of knolls and plateaux of sand and gravel, the whole being underlain by boulder-clay near sea-level.

Immediately south of Seascale the drifts consist of alternations of sandy boulder-beds and streaks of stony-clay loam. Boulders on the beach reach 3 feet or more in diameter, and pieces of St. Bees Sandstone were found measuring up to 2 feet in greatest diameter.

Criffel Granite occurs as far inland as Gosforth, immediately north of which place boulder-loam and sand, beneath fine sand and gravel, rest directly upon New Red Sandstone. Lower Boulder Clay³ makes its appearance at the railway-station and on the sea-beach at Ravenglass.

(iii) Hycemoor to Haverigg.—Red boulder-clay was at one time dug at the Bootle tile-works, about a mile north-west of Hycemoor. On Hycemoor (Bootle) beach boulders of various types of volcanic rock and of Eskdale Granite, up to 2 feet in length (near low-water mark—9 feet), were collected. Smaller granites and porphyrites resemble those of Dumfries and the north-west of Scotland. Ennerdale Granophyre was also found. Among the sedimentary rocks were boulders of St. Bees Sandstone, up to 8 inches in length, and yellow and purple micaceous sandstones, enclosing small flakes of red marl. Coarse grits, grauwackes, purple and green-banded grits and mudstones, and greenish hornfels, with glacial striae, were also represented.

About a mile farther south the low cliff consists of 12 feet or more of tough red sandy clay, sometimes with a sandy top. It contained boulders throughout, one of St. Bees Sandstone being 18 inches long. South of the River Annas, near Annaside, the cliff, which is there 82 feet high, consists chiefly of red loamy clay capped by yellowish sand. About 20 or 30 feet above the beach there is a coarse conglomeratic boulder-bed 4 feet thick. Some 80 yards farther south the cliff is capped by a grey clay; while the beach is strewn with large fallen calcreted blocks of the conglomerate, which is continuous in the clay for quite a mile farther. A boulder of Eskdale Granite measured 12 × 12 × 8 feet.

¹ D. Mackintosh, 'On the Origin of the Drifts, so-called Moraines, & Glaciated Rock-Surfaces of the Lake District' *Geol. Mag.* vol. vii (1870) p. 459.

² *Id.* 'On the Drifts of the West & South Borders of the Lake District, & on the Three Great Granitic Dispersions' *Ibid.* vol. viii (1871) p. 250.

³ *Ibid.* p. 254.

At Gutterby Lane End (near Gutterby Spa), where the cliff is 80 to 90 feet high, the following section was exposed :—

	Thickness in feet.
Red loamy clay, often stony, with seams of sand	20
Sand and gravel, with fine sand at the base.....	30
Thin bed of marly and loamy clay	1
Sandy boulder-bed with shell-fragments ¹	6-8
Sand	8
Sandy boulder-bed with shell-fragments ¹	3
Sand	10
Stiff brown stony clay seen in the base of the cliff.	

The Upper Boulder Clay is in places very similar in appearance to the Lower, which is loamy and pale red about 160 yards to the south-east of this exposure, and 150 yards farther south rises in the cliff and becomes reddish brown.

In the boulder-bed there are thin seams with pebbles and fragments of coal up to 6 inches in length. Small pebbles of banded Criffel Granite occur occasionally, and St. Bees and yellow marly sandstones are quite common. Quite three-fourths of the large boulders on the beach are volcanic; others are chiefly Eskdale Granite and St. Bees Sandstone (the latter up to 2 feet in size).

Continuing south-eastwards, stratified sands and boulder-beds occupy the

Fig. 2.—The drift-plain seen from Silcroft beach, looking northwards. Black Combe is on the right.

¹ *Turritella communis* Risso, *Buccinum undatum* Linn., *Anomia ephippium* Linn., *Ostrea*, and *Mytilus edulis* Linn. Determined by Mr. H. A. Allen.

middle of the cliff, and occasional boulders of Criffel Granite occur as far south as Townend Bank. The red loamy Upper Boulder Clay ends at the southern extremity of Townend Bank; while red sands and gravels appear at the top of the cliff, and extend nearly to its base, which consists of reddish boulder-clay. The stratified false-bedded sands are of various degrees of fineness and colour, and have variegated sandy loams and clays interbedded with them.

In Silcroft brickyard there is an exposure of about 12 feet of salmon-tinted loamy Lower Boulder Clay, containing very few stones. In addition to a few volcanic boulders, there were slate and coal fragments, some well-striated fine grits, and a small boulder of Criffel Granite. At the clay-pits east of Whitriggs Close, Haverigg, the section consists, in the lower part, of a red loamy clay with small stones and boulders and a few sandy laminæ. The upper 12 feet is chiefly yellow sand, with streaks of clay, beneath a capping of dull chocolate-coloured clay with a few stones.

VII. THE LOWER BOULDER CLAY.

(1) The Coast-Sections.

It thus appears that Mackintosh's three divisions of Lower Clay, Middle Sands, and Upper Clay, although one member or another may be missing, hold good in the main; but the lateral and vertical variations in character, and the changes in level of the drifts, are probably much greater than he imagined, and the facts are not compatible with his theories concerning their mode of formation. The passage, for example, of a lower brown till, which rises above high-water mark at Gutterby Banks, into a reddish loamy clay within a space of a few yards is more suggestive of the action of an ice-sheet that has picked up materials of diverse character and incorporated them in its ground-moraine, than of deposition in water. The whole series, as Mr. Lamplugh has pointed out,¹ is strikingly similar to that of the Extra-Insular Drift of the Isle of Man described by him in these terms:

'the whole [that is, the three divisions] are so intermingled and so interchangeable that, so far as the beds above sea-level are concerned, we can scarcely escape from Mr. [P. F.] Kendall's conclusion that the Manx drift forms one great irregular series.'

After expressing the view that both the Extra-Insular drift and the Local drift of the Island were practically contemporaneous, and both the product of land-ice, he concludes that (*op. cit.* p. 356)

'Whatever explanation is adequate for the Isle of Man will be capable of wide application'

to this and other areas.

The Middle Sands and Gravels I consider to have been formed during the waning of the ice-sheet, preceding a slight advance

¹ 'The Geology of the Isle of Man' Mem. Geol. Surv. 1903, p. 335.

which introduced the Upper Boulder Clay. These events will be discussed more fully at a later stage.

Some of the inland sections where the Lower Boulder Clay rises up the flanks of the hills, and rests upon granite, volcanic rocks, or slate, will now be described. These sections show the dovetailing of drifts of distant and of strictly local origin¹; but this, as I have shown above (p. 411), does not in all cases imply an intermixture of Irish-Sea and Lake-District drift.

(2) The Inland Sections.

(i) North of Bootle.—Upon the granitic tract north-east of Bootle the drift which passes for Boulder Clay is largely composed of granitic débris, and is difficult to separate from the later fluvioglacial sands and gravels. It contains included streaks of red loamy clay in a few places, with, among others, small boulders of St. Bees Sandstone (Park Nook, near Bridge End). In the later fluvioglacial gravels of this area, formed chiefly from

Fig. 3.—Section of Boulder Clay near Fell Green, Bootle, looking eastwards.

[1=Rusty coloured sand; 2=Yellowish-red or brown, rather sandy clay, with red clayey patches; 3=Grey-brown sandy clay, with fairly numerous Skiddaw Slate fragments: some parts gravelly; 4=Red sandy loam.]

washed and re-sorted Lower drift, boulders of St. Bees Sandstone were also found, a little farther east than Corney. The valley of the Kinmont Beck east of Low Kinmont was filled with drift chiefly of granitic origin, sometimes of a clayey but more often of a loose texture. The head of Damkirk Beck, a mile east-north-east of Bootle, is cut partly in a rich red Triassic boulder-clay with greyish patches of granitic débris.

Dovetailing of the drifts is well shown in a section at the head of the Fell Road to Broughton, about 150 yards south-east of Fell Green, east of Bootle (fig. 3). Granites are common in this section, and there is the usual suite of volcanic rocks, among them an

¹ For a comparison, see the description of the lateral moraine of the Von Post Glacier, Spitsbergen, by Mr. G. W. Lamplugh in 'The Shelly Moraine of the Sefström Glacier, &c.' Proc. Yorks. Geol. Soc. vol. xvii, pt. iii (1911-12) pp. 237-38.

agglomerate with included fragments 6 inches in length. There are a few boulders of soft red sandstone, and many well-striated Skiddaw Slates from the neighbourhood of Cleator and Ennerdale.

(ii) Western slope of Black Combe.—The Lower drift rises from a level of about 250 feet near Fellside (half a mile east of Bootle) to a height of over 400 feet near Whitbeck, falls to 200 feet near Sledbank, but rises again to 300 feet at the mouth of the Whicham Valley. Skiddaw Slate *débris* becomes an increasingly important constituent in a southerly direction, but there is a great amount of Triassic *débris* throughout, as well as granitic and andesitic material of all sizes.

Between Fellside and Hall Foss (a mile south-east of Bootle) the Boulder Clay is very sandy, and the hillside above its level has been scraped and polished by southward-moving ice which left erratics and perched boulders upon the slopes above (p. 422). Between Hall Foss and Hole Gill the lower slopes are also scraped and steepened, and boulders occur in the lower part of Hall Foss above the level of the clay. A section near the footpath on the northern side of Hole Gill Beck shows the interweaving of drifts—chiefly brown and sandy at the western end, with slate-grey material in the middle, and clayey drift with very little slate at the eastern end. A pit on the south side shows variegated drift with much slate-*débris*.

A platform, the scarped face of which (pp. 434–35) is situated from 50 to 100 yards west of the footpath, consists of unstratified drift of a sandy texture, containing a considerable amount of slate. Boulders of slate also lie on its surface. Near Monkfoss Farm, 300 yards from the bare hillside, the drift is brown and sandy, but unstratified.

The lower of two pits by the road south of Whitbeck Mill showed 12 feet of brown gritty boulder-clay, with much slate-*débris*, resting on a foot or more of red sandy drift containing lumps of red sticky loam and fragments of red sandstone and shale. The bottom of the further pit was almost on a level with the top of the last. It exposed 12 feet of more homogeneous brown sandy drift full of stones, mostly of slate, but there were also boulders of granite, etc. A tawny-yellow sand (probably rainwash) following the slope of the hill crossed the edges of the deposits, in both sections, obliquely. The slaty fragments in the drift north of this point were mainly of the pale unbanded felspathic type; in these sections, however, the blue banded slates begin to appear, and are quite common farther south.

In Miller Gill, behind Whitbeck Mill, there is a beautifully glaciated surface of slate, from which the boulder-clay has been stripped away; and 150 yards upstream is a second, the direction of ice-movement in both cases having been to the south-east.

A pit about 440 yards south-south-east of Whitbeck Church shows 10 feet of slaty drift, with patches or streaks of loam and red clay. Another section about a third of a mile to the south

shows a similar admixture, and contains a few boulders of Triassic sandstone.

There is an interesting section near a quarry in a dyke on the hillside above Wood House. The Boulder Clay, which rests upon a smoothed and striated surface of Skiddaw Slate, is a composite mixture of variegated drift, as shown in the appended section (fig. 4). Boulders of slate are beautifully striated.

Fig. 4.—Section in Boulder Clay near Wood House, Whitbeck, looking southwards.

[1=Roughly-stratified slaty drift, with boulders: matrix brown and gritty, sometimes approximating to a gravel; 2=Yellowish loam, with fewer stones, but more of large size and distant origin than in 1; 3=Strip of brick-red sand with stones; 4=Tawny-coloured sand with stones resting upon 1 & 2 in a 'pocketty manner.' At the bottom (left) of the section, the clay (1) rests upon a glaciated surface of Skiddaw Slate.]

Near Sledbank there is an admixture of slaty and red-clay drift, with sandy and gravelly layers streaked out in a south-easterly direction. It is overlain by 2 feet of tawny-yellow sand, and underlain by a similar thickness of warm red sand, both containing stones. The boulders are chiefly slates, lavas, tuffs, ashes, and Eskdale Granite, some of the latter being very rotten. Boulders of Ennerdale Granophyre and St. Bees Sandstone were also noted.

(iii) Whicham to Duddon Estuary.—The Boulder Clay, swinging round the shoulder of Black Combe, is traceable to the back (west) of Whicham Rectory, and next appears upon the opposite side of the valley south of Pohouse, about a mile from the valley-mouth. Under Nicle Wood and Lacra Bank it is rather sandy, and contains slates, red sandstone, granites, granophyres, and volcanic rocks. On the western slope of Lacra Bank it is largely composed of the underlying slates, and rises to over 300 feet; it sinks to below 200 feet under Kirksanton Bank, but granite boulders are found as high as 400 feet. On the south-eastern slopes of Harrath Hill (west of Millom) the drift is reddish, and granite boulders rise no higher than 200 feet.

At King's Quarry, Millom, more than 4 feet of red clay rests upon the Coniston Flags, and Mackintosh¹ records red clay with boulders of Eskdale Granite, resting upon a beautifully striated surface of Carboniferous Limestone (about half a mile south of the station), in which most of the striations point north-eastwards. He concludes that the glaciating agent and the carrying agent were not the same, assuming that the glaciating agent moved in a south-westerly direction out of the Duddon Estuary. On the contrary, however, the granitic drift of the maximum glaciation was carried some distance up the centre of the Duddon Estuary,² and appears again at 70 feet above sea-level on Dunnerholme, upon the east side of the estuary. Mackintosh³ however, describes it as being Upper Boulder Clay 2 to 5 feet thick—a red loamy clay,⁴ well charged with rounded and half-rounded stones, slate, porphyry, and granite, many much more rounded than those at the base of the cliff. Granites also occur over the ground stretching a mile north-east of Dunnerholme; and at a small quarry near Gargreave, about 250 feet above the sea, the slates were planed down and slightly grooved 10° west of north.

VIII. DISTRIBUTION OF SCOTTISH BOULDERS.

The distribution of boulders of Criffel Granite in the drifts of the coast, as a whole, has been so fully described by Mackintosh and others⁵ that I need say no more than that my own observations confirm or strengthen those of previous investigators. North of the district here described the eastern boundary of the Criffel Drift

¹ 'On the Drifts of the West & South Borders of the Lake District, &c.' *Geol. Mag.* vol. viii (1871) pp. 304–305. This may be the exposure at Redhill Quarry shown on the 6-inch Geological Survey map, about three-quarters of a mile south-south-east of the station.

² The Irish-Sea ice seems to have received its tributaries on the outer sides of convex bands, in much the same way as some rivers do. Mr. J. D. Kendall recognized that the boulder-current was deflected up to the Vale of Duddon near Millom.

³ 'On the Correlation, Nature, & Origin of the Drifts of North-West Lancashire & a Part of Cumberland, &c.' *Q. J. G. S.* vol. xxv (1869) p. 425.

⁴ The kind of Lower Boulder Clay that we might expect to find in such a position.

⁵ See references on p. 403.

coincides with the main road between Egremont and Ravenglass, after which it follows the railway to near Silecroft. I have seen boulders of the granite as far south as Silecroft, and they have been recorded by Mr. J. D. Kendall¹ near Whicham Hall, and by Charles Smith² near Millom (see also p. 444). With the exceptions stated below, most of the other boulders in the drifts south of Bootle were derived from Cumberland, or from the seabed off the Cumberland coast. On the beach at Hycemoor (near Bootle Station) grits and grauwackes, like those of the South-West of Scotland, are of common occurrence, and so too are porphyrites similar to those of Dumfries. Grauwackes also occur on Silecroft beach, and seem to extend as far eastwards as the Criffel Granite. I found several east of Nicle Wood on the eastern side of the Whicham Valley, near its mouth, and boulders also of Scottish porphyrites, both here, and near Whicham (compare the Castle-Douglas porphyrites). On Bootle Fell there was a hornblende-granite similar to a Galloway granite, and near Whitbeck some of the boulders are of the Dalbeattie or Cairngall Granite types.

No boulders of Ailsa Craig microgranite were seen.

IX. PHENOMENA OCCURRING DURING THE RETREAT OF THE ICE.

(1) Moraines and Trails of Boulders.

Between the 500- and 800-foot contours, on the slopes of Stainton Fell, south of the mouth of Eskdale, there is a series of low morainic ridges, about a mile in length, trending south-south-westwards, and breached near the centre by Stainton Beck. Farther south a splendid moraine, with the same direction, descends to, and follows, the 700-foot contour for more than a mile, to a point about half a mile east-south-east of High Corney. Another, south-east of High Corney, lies between 500 and 600 feet.

The slopes of Waberthwaite and Corney Fells, between 700 and 1000 feet, are covered by a series of less perfect, but quite distinct, moraines, or morainic terraces, trending north and south, formed as the ice slowly withdrew by lateral shrinkage. Thicker deposits of Boulder Clay lie at a lower level between the steeper hill-slope with moraines above, and the channelled granite-plateau below, which, with its gravelly covering, reaches a height of between 400 and 500 feet. These moraines were left by Lake-District ice, confluent with the Irish-Sea ice.

West of Buckbarrow Beck, near its junction with Kinmont Beck, the moraines take a south-westerly trend, crossing the contours nearly at right angles. The valley of the Kinmont Beck was choked by drift, and is now being re-excavated, the relics of infilling material being re-arranged and redistributed by the stream as a series of terraces (Pl. XLI, fig. 1). On Bootle Fell ridge-

¹ 'Distribution of Boulders in West Cumberland' Trans. Cumberland Assoc. pt. v (1879-80) p. 155.

² 'Boulder Clay' Trans. Cumberland Assoc. pt. iii (1877-78) p. 103.

shaped lateral moraines occur on and above the 700-foot contour, with a north-and-south trend, but swing round to the south-west and west, and cross the contours immediately south of the Fell road from Bootle to Broughton.

Fig. 5.—Moraine near High Corney, Corney Fell, looking north-north-eastwards.

[This moraine has a ridge-like top, and is more than a mile long.]

No true moraines were seen upon the western slopes of Black Combe, for the steep descent and the general absence of ice-free ledges would probably forbid any great accumulation of morainic matter. On Butcher's Breast, however, Eskdale Granite and Borrowdale erratics are clustered between the 600- and 700-foot contours, and there is another patch above the 1000-foot level north of the head of Hallfoss Beck.

South of Monkfoss Beck,¹ also, is an interesting trail of boulders, of the nature of a moraine, between the 800- and 1000-foot contours. The erratics consist chiefly of boulders of Eskdale Granite,² the largest of which, the 'Broughton Stone,' measures $8 \times 9 \times 5$ feet, while another measures $6 \times 5 \times 3$ feet. There are also boulders of andesite, volcanic breccia (7 feet long: probably from Caldbeck, containing fragments averaging 4 to 6 inches in length, but up to 2 feet maximum), banded ashes, and pale quartz-porphyrty like that exposed at the foot of Hogleigill Beck.

Small moraines occur in the Combes upon the south-east side of Black Combe; but, since they belong to a late stage of the glaciation, they will be referred to in another section (p. 446).

The Whicham and Duddon Valleys are, on the whole, free from moraines, but in the latter there is (about 8 miles due east of the mouth of Eskdale) a

splendid example of a lateral moraine under Walna Scar near Seathwaite. Mackintosh³ describes this 'great wonder of the Duddon Valley' as a post-marine lateral moraine, probably formed by a shallow glacier.

¹ Mackintosh refers to an 'ice-floe load' of boulders on a plateau, on the south side of the upper part of Foss Beck, at a height of about 1000 feet, discovered by Mr. Eccleston of Carlisle: he probably alludes to this group. See *Geol. Mag.* vol. viii (1871) pp. 253, 256.

² Mr. J. D. Kendall also records boulders of Eskdale Granite at 1000 feet. See *Trans. Cumberland Assoc.* pt. v (1879-80) p. 155.

³ *Geol. Mag.* vol. viii (1871) pp. 306-307.

It is about 2 miles long, and occurs in three main sections. Commencing on the north between the 800- and 900-foot contours, it descends to near the 500-foot contour about half a mile south-south-east of Seathwaite Church. The southern section, east of Seathwaite, has moutonné rock-surfaces protruding through it at its southern end. The middle section is similar, but conceals the rock-surface more thoroughly. South of Long House Gill, this section is most prominent near the top, where it forms a broad terrace. It consists of a tumultuous accumulation of huge sub-angular boulders which cover a considerable part of the hillside, and enclose many a marshy flat or swamp. The third section, north of Long House Gill, is more ridge-like, and divides into two mounds, covered with great angular blocks, many of which are of banded ash.

The moraine lies in an embayment where the contours on opposite sides of the Duddon Valley widen out. This widening doubtless caused a state of semi-stagnation, or, at any rate, of slow movement, in the ice on this side of the valley, resulting in the accumulation of surplus débris.

(2) Marginal Channels and Associated Sands and Gravels.

Before the Ice Age, the normal drainage of the country lying between the Duddon Estuary and the Esk was westerly or south-westerly. The Esk and the Whicham Beck, for example, flowed to the south-west, and the Kinmont Beck, near Bootle, to the west of south-west. Thus the main drainage then, as now, occupied channels running nearly, but not quite, at right angles to the coast-line, which trends slightly east of south.

There is, however, another series of channels, which are now for the most part either dry, or occupied by insignificant streamlets¹; while their general trend corresponds more or less with the trend of the moraines upon the hillsides north and east of Bootle (p. 421).

In some cases the channels were merely carriers of the marginal drainage of the ice-sheet—now in the ice, now in the rock, or between the ice and the rock-face. In other cases they represent channels scoured out by overflow waters, from lakelets held up between the ice-front and embayments of the land.

As the position of the ice-margin altered from time to time, new channels were developed, so that two or more courses were sometimes formed in parallel sequence at consecutively lower levels. 'In-and-out' channels, and channels formed entirely in drift, or between an ice-wall and a drift-wall, are also represented.

(i) The Granite Area south of Eskdale.

The shelf-like western part of the granite outcrop (see p. 406) between Eskdale and Kinmont Beck is about a mile wide, and

¹ The River Annas being an exception.

slopes gently westwards from near the 500-foot contour to the 300-foot contour, from which it drops abruptly to the 200-foot level.

During the maximum extension of the ice the surface of this shelf was, like the slopes above it, covered mainly by boulder-clay of a somewhat sandy type (see p. 417). The retreat of the ice seems at first to have been unaccompanied by any great melting, but rather by evaporation, coincident with a falling-off in the amount of precipitation: for no signs of water-action at the margin of the Irish-Sea ice appear in this district above the 500-foot contour, although, apart from the ice itself, the gathering ground was large enough for water to be set in motion, had the snow-line been at a higher level.

When appreciable melting did take place, moving water began to modify the drift previously deposited upon the shelf or held in the melting ice; and, since this drift consisted largely of sandy Triassic waste, with granitic and volcanic débris, the resulting products are mainly of a sandy and gravelly nature.

For example, one of two pits, situated by Whatson Beck, nearly three-quarters of a mile north-north-east of Welcome Nook, shows 6 feet of false-bedded sand with gravelly layers, capped by about 3 feet of gravel, some layers of which are disintegrated granite. In the middle of the pit, about 3 feet of red stony clay rests on sand and gravel, and passes laterally into the same. At the top are some large boulders. Sections of a similar nature were seen at several points, as, for example, about a quarter of a mile south-east of Row, near Welcome Nook; 100 yards east of Park Nook; near Low Kinmont, and Kinmont Wood. In a pit near the 'Camp,' about 500 yards north-north-west of Corney Church, there was more than 20 feet of coarse roughly-bedded gravel, most of which is bound together by red muddy silt, but there are also beds of cleaner sand and gravel. Some fairly large erratics and pebbles of red sandstone were also noticed here. The gravel extends southwards to and beyond the neighbourhood of Corney Hall, where it forms a distinct feature above the granite, and is exposed a few yards north of the Hall in a pit in which 3 feet of coarse false-bedded granite sand overlies more than 6 feet of gravelly boulder-beds, on a similar deposit at a lower level. In all these cases the well-worn character of the gravel shows that the majority of the pebbles had been carried a long distance by running water before being finally deposited.

The method of occurrence and nature of the above-described deposits suggest that they were accumulated, as a lateral apron or fan, at the oscillating edge of the ice-sheet, by waters which slowly escaped in a southerly direction through indefinite or now-destroyed channels in the drifts.¹ At the same time, the more clearly-stratified portions were doubtless formed in temporary marginal lakes. As

¹ The method of formation of such gravels was discussed by the late Prof. Ralph S. Tarr in 'The Yakutat Bay Region, Alaska' U.S. Geol. Surv. Professional Paper 64 (1909) chapt. ix.

time progressed definite channels were cut through these first-formed deposits, in many cases into solid rock, by swiftly-running streams carrying a full burden of gravel and gritty sand.

(a) The Barnscar Channel.—The first of the drainage-channels to be described occurs about a mile north-east of Bridge End, east of Eskmeals Station. It is a shallow trough in granite, 20 to 30 yards wide, with a dry flat bottom, except at its southern end, where a small stream rises and joins Black Beck on an alluvial flat near Stainton Farm. This channel was probably excavated by the water which cut the channel that will be next described. The ground between them is low, and was occupied either by a small lake, or by a lobe of ice through, or across, which the water flowed. (See map, Pl. XLIII.)

(b) The Kinmont (Welcome Nook and Low Kinmont) Channel.—This channel commences rather vaguely, as a dry valley, near Grange Farm, just above the 400-foot contour, about three-quarters of a mile south-east of Bridge End. Immediately south of Welcome Nook, however, where it makes a bend to the east round a rather steep hillside more than half a mile from its head, it is quite prominent. The flat marshy alluvial bottom, about 90 yards wide, is traversed only by a narrow drainage-ditch, almost too small to carry off the accumulated water (Pl. XLI, fig. 2). The floor of the channel crosses the 400-foot contour at Welcome Nook, and the depth of the valley is from 60 to 70 feet. The walls then become less prominent, but south of the point where the River Annas crosses the valley near Foldgate, the profile of the (now dry) valley becomes once more pronounced. A few small hanging becks then tumble into the valley, and unite to form a little tributary to Kinmont Beck. Granite is exposed at several points, but especially near Low Kinmont, where the valley, which is quite 30 feet deep, comes to an end, its floor being slightly above 300 feet O.D. The channel is thus about $2\frac{1}{2}$ miles long, and its floor falls 40 feet per mile.

(c) The Corney Channel.—At an average distance of a third of a mile west of that just described, another channel is still more strikingly developed. Commencing in granite, well below the 400-foot contour, at a point almost due west of Welcome Nook, it makes a convex bend to the west for half a mile, and then turns southwards, its floor crossing the 300-foot contour about a quarter of a mile north of Gillfoot, near which place it is fully 100 feet deep and quite dry.

The River Annas enters on the east immediately south of Gillfoot, through a steep-sided gorge which forms a cross-cut from the Kinmont Channel near Foldgate. An alluvial cone is thrown across the valley by the river, which then turns southwards. At the southern point of entry of the river, boulder-beds (with St. Bees Sandstone) capping stratified granite-sand were noticed, resting

upon a cliff of rotten granite. On the opposite side of the main valley, 3 to 4 feet of red and yellow stratified granite-sand, with a south-easterly dip and embedded boulders, was exposed in the road-bank facing Skellerah House. The valley is 40 to 50 feet deep at Corney Mill, where 15 feet of boulder-beds and stratified sand rest upon more than 20 feet of exposed granite.

At Corney Hall, a low col gives access on the west to a transverse valley, about a fifth of a mile long, which is of a similar nature to that near Gillfoot and will be dealt with later on (pp. 426-28). About 100 yards south of Corney Hall there is a drop in the floor of the main channel, the depth of which increases to 100 feet, and its drift-capped sides become steeper. At Black Dub the floor crosses the 200-foot contour and turns abruptly westwards, round Seaton-Hall Wood, leaving the outcrop of the granite. South of this point the eastern granite-wall of the old channel, as far as Kinmont Beck, is still in existence; but the western wall is wanting, and was evidently formed of ice.

The complete channel is nearly 2 miles long, and its floor falls about 75 feet per mile.

(d) The Near-Bank 'in-and-out' Channel.—A third channel as long as, or longer than, the last, lies still farther west, its general course coinciding with the western outcrop of the granite which descends quickly from 300 to below 200 feet. The ice apparently rested for a considerable time against this slope, and steepened it by holding flowing water against it. At Near Bank, owing to the crowding of the ice, the water was forced to cross a spur of granite, and cut a splendid example of an 'in-and-out' valley about a quarter of a mile long. Its floor is 50 yards wide, and lies below the 200-foot contour; while its eastern wall is over 60 feet in height. A small stream dropping into the valley from this side throws across the floor a low delta, upon which the stream turns and takes a southerly course (Pl. XLII, fig. 2).

(e) The Gillfoot and Corney-Hall transverse channels.—The valley which introduces the Annas into the Corney Valley is rather steep-sided, and some 300 yards long. In this distance its floor falls about 50 feet, its almost abrupt descent being at the western end, where it drops into the Corney Valley. It connects the Kinmont Channel, the floor of which lies at from 360 to 370 feet above O.D. (the River Annas is at about 350 feet), with that of Corney, a little below 300 feet.

At Corney Hall there is a similar (but dry) valley, a quarter of a mile long, connecting the Corney with the Near-Bank Channel. At its head, immediately west of Corney Hall, is a low col, from which the floor of the cross-cut descends over 60 feet in a westerly direction. At its best the valley is quite 80 feet deep. Stratified sand and gravel occur in the wood on the southern slope at a rather low level, perhaps deposited in a small pre-Glacial stream-hollow (Pl. XLII, fig. 1).

Were it not for the transverse valleys at Gillfoot and Corney Hall, there would be nothing inconsistent in the view that the parallel sequence of channels—Kinmont, Corney, and Near Bank—was formed during a retreating movement of the ice, after it had advanced over the gravels which it had previously deposited, because the heads of the three longitudinal channels are so related to the contours that each would have come into operation after the next above it had been abandoned. The transverse valleys, however, seem to show that different parts of the longitudinal channels were cut at different times.

Assuming first that the ice, after an advance over the gravels, was retreating, and that the Kinmont Channel was cut, the formation of the Gillfoot cross-cut would require a small retreat of the ice, and a filling up of the lower part of the Kinmont Channel, so that the water would be compelled to flow over a low col, or along a pre-Glacial hollow, on the site of the Gillfoot Channel; and then, following the ice-margin, commence to cut that part of the Corney Channel which is south of Gillfoot. This result might conceivably be brought about by snow filling the lower part of the Kinmont Channel—local glaciation being out of the question. Further retreat of the ice-margin would cause the water to abandon the upper part of the Kinmont Channel and open up the whole length of the Corney Channel, which would be cut almost to its present low level. The formation of the Corney-Hall Channel may have been due to a similar process, the col at the Hall being formed by an oscillatory movement which threw the waters back for a short time from the Near-Bank Channel into the Corney Channel.

There is, however, a second possible explanation, namely, that the parallel sequence was cut during the forward movement of the ice when it overrode the gravels. It has been recently demonstrated¹ that a slight advance of a glacier is often followed by

Fig. 6.—Profile section of the parallel sequence of marginal channels in the granite north of Bootle.

¹ O. D. von Engeln, 'Phenomena associated with Glacier-Drainage & Wastage' Zeitschr. für Gletscherkunde, vol. vi (1911) pp. 128, 129.

the development of a visible marginal drainage, chiefly because of the choking and blocking of the courses previously occupied by the flowing water. A further advance may then force the stream to occupy a channel higher up the slope against which the ice is resting. In this case the stages of development would be as follows:—after the formation of the Near-Bank Channel the ice north of Corney Hall, advancing obliquely across the contours, caused the water to flow by way of the Corney valley and by a low col at Corney Hall, that is, along two sides of a right-angled triangle, of which the ice-margin formed the hypotenuse. A further advance would block the Corney-Hall transverse channel and the intake of the Corney Channel, and throw the water into what is now the Kinmont intake. It would then flow by way of the upper half of the Kinmont Channel and the Gillfoot notch into the lower part of the Corney Channel, and cut that part of the latter which lies south of the Corney-Hall intake. Further advance of the ice would account for the excavation of the lower part of the Kinmont Channel.

This explanation, in itself, postulates that the ice, in its advance, did not (although in all probability it would) fill up any of the overridden channels with morainic deposits, for they are, at present, quite empty and bare. If, however, the water occupied each channel a second time, during the withdrawal of the ice, it may have cleared them of all obstructive material.¹ In discussing, in the following paragraphs, the marginal channels in the volcanic tract south of Kinmont Beck, it will be seen that there is reason to believe that they were chiefly cut during an oscillatory retreat of the ice which followed upon a slight advance over the gravels. I am, therefore, inclined to think that the main cutting of the channels in the granite also was accomplished during retreat; but this need not prevent us from assuming that the watercourses may have been first blocked out during advance.

(ii) The Volcanic Tract east of Bootle.

During the maximum extension of ice, the volcanic tract near Bootle, together with those parts of the granite and slate areas which immediately bound it on the north and south, were covered by boulder-clay, which levelled up the hollows so that the surfaces formed of drift and solid rocks were in some cases continuous. The retreat of the ice after the formation of the moraines was, as before, marked by the accumulation of much fluvio-glacial material, which now lies sometimes on solid rock.

The upper limit of this drift can be traced, just below the 500-foot contour, on the lower slopes of Bootle Fell (Damkirk Brow). The sands form two bold esker-like ridges (North and South Coppycow) on the moorland above the 400-foot contour south of Damkirk Brow, their striking shape being probably due

¹ For a description of the cutting of a complex series of marginal channels by alternations of advance and retreat, see *op. supra cit.* p. 130.

to denudation. Beds of sand and gravel also occur on the south side of Grassoms Beck, a few hundred yards east-south-east of Gibson's Spout; and on Bootle Bank they form a rather flat-topped feature, rising from a platform of andesite to 400 feet at its highest point (fig. 10, p. 432).

A pit at the northern end of the feature gave the following section:—

	<i>Thickness in feet.</i>
Layers of stratified sand and gravel, with boulders measuring up to 18 inches in greatest diameter	15
Well-stratified red [Triassic] sand and finer layers of gravel, chiefly of granite, lava, ash, etc. with occasional boulders.	4

The pits on Bootle Bank also contained fragments of red sandstone and striated slate.

These gravels are comparable with those described above as having been formed on the granite tract, but they differ in their more regular stratification and by lying at a higher general level.

Fig. 7.—*Profile section of the parallel sequence of marginal channels in the volcanic rocks near Bootle.*

They were probably accumulated beneath the waters of an ice-dammed lake about half a square mile in extent, held up in the embayment north of the north-western shoulder of Black Combe. The water drained away through, or over the ice, leaving no trace of its exit.

At a later stage, about the time when the Kinmont Channel was first initiated, and when a small lake probably existed at its lower end, these gravels began to be degraded and removed by a definite stream which finally cut the Damkirk Channel through the underlying andesite.

The andesitic ridge would form a more formidable barrier than the granite, for the rock decomposes less easily, and would not have been so thoroughly rotted to begin with. Consequently the drainage-channels are narrow and steep-sided, and begin and terminate rather abruptly, for the drift banked against the ridge has been to some extent removed by post-Glacial erosion.

As the water-level fell, roughly stratified or false-bedded gravels were formed at successively lower levels near the heads of the drainage-channels. A section 8 feet or more in depth, at the head of the Bramire Channel, shows sand and gravel with boulders up to 2 feet in greatest diameter, on coarse sand and gravel, resting upon fine sand and gravel inclined in a south-south-easterly direction,

Fig. 8.—*The Damkirk Channel, Damkirk Bottom, looking northwards, with the delta of Old Close Gill in the right foreground.* (See pp. 431–32.)

that is, towards the head of the Nettle-Crags Channel. The boulders are chiefly of Eskdale Granite and Borrowdale rocks, but there are also small boulders and pebbles of soft Triassic sandstone and Skiddaw Slate. Another pit showed a similar section, consisting to a great extent of big granite-boulders in granite-sand. Many of the granites were quite rotten, and crumbled beneath the fingers.

(a) The Damkirk Channel.—At the time of the initiation of this channel the ice-margin, after a very small advance over the gravels, lay in an almost north-and-south line between the western side of the Kinmont Channel (350 feet approximately), Bootle Bank (350–386 feet), and the shoulder of Black Combe, holding up a small lake north of Bootle Bank. The outflow was first cut through drift, but was finally sunk into the rock-floor. The intake faces west, but the channel turns quickly southwards after crossing the junction between granite and andesite.

At its head the Damkirk Beck enters by a post-Glacial course, and traverses Damkirk Bottom as a stream hardly more than a foot wide, and an obvious misfit. At this part of its course the channel is a steep-sided flat-bottomed valley, about 45 yards wide and fully 70 feet deep. A few yards north of the road

Fig. 9.—*The Nettle-Crags Channel, looking northwards.* (See p. 432.)

[The original steepness of the walls is obscured by screes.]

over Damkirk Brow it receives Oldclose Gill, which enters from a post-Glacial ravine, and throws an alluvial cone across the valley floor, forming a marshy tract to the north of it, which Damkirk Beck is powerless to drain thoroughly (fig. 8, p. 430).

After crossing the road the main valley makes a bend to the south-east, receiving Grassoms Beck which cascades into it at Gibson's Spout. This is joined by Damkirk Beck, and the combination, under the name of Crookley Beck, traverses the valley (here cut along the junction between andesite and slate) and leaves it, on its western side, at Cat Crag, by its re-excavated pre-Glacial gorge. The Glacial channel then swings to the south, its marshy floor being slightly above the present alluvium of Crookley Beck.

The channel is five-sixths of a mile long, and its floor falls from 320 to 200 feet, that is, 144 feet per mile.

(b) *The Nettle-Crags Channel.*—This is a dry valley which lies directly in line with the Kinmont Channel, and is connected with it by a boulder-strewn hollow in the drift. Commencing in drift-covered granite, it becomes pronounced where cut in andesite, the western wall forming a precipitous crag some 50 feet high (fig. 9, p. 431).

Near Nettle Crags the main channel divides, and encloses an island formed of banded ashes.

At its head the floor is nearly 30 feet below the Damkirk intake; but, since the valley is fairly shallow at that point, there is every reason to suppose that its initiation led to the abandonment of the Damkirk Channel. It is half a mile long, and its floor descends about 90 feet, that is, at the rate of 180 feet per mile.

(c) *The Bramire-Wood Channel.*—This channel runs from north to south, close to, and nearly parallel with, the Nettle-Crags Channel. It also commenced in drift-covered granite,

Fig. 10.—*Bramire-Wood Channel, looking eastwards.*

[The Nettle-Crags Channel is in the middle distance. A feature is formed by the gravels of Bootle Bank on the sky-line. A cross-cut between the two channels occupies the centre of the picture. Black Combe is on the right.]

becoming pronounced after it crosses the boundary and enters the andesite. Its bottom is quite flat and dry throughout the upper half of its course, below which, however, there is a small drain. About half-way down the craggy eastern wall is 80 feet or more in height; the western side is mostly drift-covered (fig. 10, above). The floor falls from 270 to 180 feet, or at a rate of 180 feet per mile—about the same rate as the last.

The relationships between the Bramire and Nettle-Crags Channels seem to have been complicated by oscillatory movements on the part of the ice-margin, and different portions of both channels may

have been in operation at the same time. After the Nettle-Crags Channel had been cut to a shallow depth, the ice appears to have retreated and allowed the Bramire Channel to be opened up. Then followed an advance which threw the water back again into the upper channel, so that its floor was lowered nearly to that of the Bramire Channel.

Withdrawal of ice from the lower part of Bramire then allowed the water to fall, by a cross-cut, into that channel, near Nettle Crags. The subsequent opening-up of the upper part, and lowering of the floor, left the connecting channel as a hanging valley, opening upon the eastern wall of the Bramire Channel. This is shown in the accompanying figure drawn from a photograph and sketch made on the spot (fig. 10, p. 432).

The three channels—Damkirk, Nettle Crags, and Bramire—form a parallel sequence cut across the ridge of Borrowdale rocks, as shown in the diagram (fig. 7, p. 429). The first two appear to have been connected with the Kinmont Channel, but the Bramire-Wood Channel was probably fed to some extent by water from the Corney Channel, and the fluctuations of the ice-margin just discussed may have coincided with the fluctuations which led to the cutting of the transverse valley at Gillfoot (p. 426).

Fig. 11.—*Tarn Dimples, looking northwards: a water-cut gash in the hillside.*

(iii) The Western Slope of Black Combe.

(a) *The Tarn-Dimples Channel.*—Tarn Dimples, situated between 200 and 450 yards south of Holegill Beck, is a notch in the hillside of rather striking appearance. From its situation, it seems certain that the mouth of Holegill was blocked by a lobe of

ice,¹ and escaping water, after passing along a rock-ledge at the south-eastern edge of the lobe, immediately above the 400-foot contour, fell obliquely and rather rapidly along the mountain-side to the 300-foot contour. The head of the notch is almost precipitous,

Fig. 12.—The Monk-Foss 'in-and-out' Channel in drift, looking north-north-westwards.

[The drift-plain is seen in the distance, and Black Combe on the right.]

and must have formed a waterfall, which would account for the hollow occurring just below it. The hollow (partly filled by scree) is boggy, and contains several boulders, which may have been swirled round and round. A 7-foot boulder of Eskdale Granite, at a slightly higher level, has probably rolled down the hillside from above. The water at first escaped by a short oblique channel directed towards the south-west; but, when, this became closed by ice, it cut a short valley running parallel to the hillside, and finally ending blindly in the open.

The crag, thus isolated, is 40 feet high, and consists of slates riddled by reefs of vein-quartz. Its outer slope when continued upwards with its natural

curve, corresponds exactly with that of the hill from which it has been severed (see fig. 11, p. 433).

Tarn Dimples is not an 'in-and-out' valley, but a rather complex 'out' valley, commencing with a waterfall.

(b) The Monk-Foss Channels in Drift.—From Fellside

¹ Boulder-clay enters the mouth of Holegill (see p. 418).

near the termination of the Damkirk Channel (half a mile east of Bootle) a hollow in the drift runs to near Far End (a third of a mile). South of this point, to Holeyill Beck, the western wall of the channel consisted of ice, and is therefore now wanting, the ground on that side falling away, as a gentle slope, to the 100-foot level. The eastern wall is a steep scarp-like bank, about 30 feet in height, running nearly to the 200-foot contour. South of Holeyill Beck it is from 40 to 60 feet high, and consists in part of boulder-clay, as described above (p. 418), and in part of unstratified sandy drift.

Between Hallfoss Beck and Monk Foss, where the bank is about 80 feet high, there is an excellent example of an 'in-and-out' valley, the isolated ridge of drift forming, as it were, the string of the bow-shaped eastern wall of the channel. The ridge resembles an esker, but its origin is clear: it represents in a different medium the severed spur of granite at Near Bank (p. 426), only in this case the western face of the ridge had been shaped by water before the advance of the ice caused the channel to be cut. With the exception of one or two runnels which fall over the eastern side, the valley is dry (fig. 12, p. 434).

Near Stangrah, immediately south of Monk Foss, there is another dry 'in-and-out' valley, over 50 feet deep, and nearly as long, but not so well defined, as that just described. This channel isolates two small hummocks of drift, separated one from the other by a low col.

Fig. 13.—*Profile section of the Tarn-Dimples and Monk-Foss Channels, and the oversteepened slope of Black Combe.*

South of this spot the course of the channel becomes vague. Thus from Fellside to Whitbeck, a distance of 2 miles, there is evidence of a marginal drainage-channel, the floor of which, starting at the 200-foot contour, falls to near 120 feet (40 feet per mile), and the western wall of which was the ice itself, except where the 'in-and-out' channels were developed.

The age of this channel was apparently about the age of the Nettle Crags (late), Bramire and Corney (early) channels.

Its comparatively low grade was doubtless due to the nature of the floor upon which the ice was resting. Steeper gradients are to be expected where ice rests on rocky and irregular ground, and gentler gradients where it covers a softer, flatter, and more easily eroded floor.

(iv) The Volcanic Tract east of Black Combe.

(a) The Millom-Park Channels.—On Millom Park there is a series of channels of a somewhat peculiar character, the best examples forming a group of shallow trenches which unite with one another, or bifurcate, in a rather inconsequential manner (fig. 14, below). They either cut across the watershed (over 500 feet), or cut obliquely into the hillside, until they meet another channel

Fig. 14.—Plan of the dry drainage-channels on Millom Park, showing the sites of the glacial lakes. (Scale=1:15,840.)

[The dry channels are dotted over, and the Gillscar Channel is shown black.]

which started at a higher level. Their average direction is north-north-easterly, and most of them existed for only a short time. Some, however, have the characteristic trough-like aspect of drainage-channels, and their floors descend in steps. Channels also occur, but to a less marked extent, in the volcanic tract north of Knott Hill. Although their directions sometimes correspond with rock-structures, this is not usually the case, and they do not occur elsewhere in similar rocks.

When the hill-tops in this neighbourhood were first uncovered, the basin south-west of Millom Park was full of ice which formed a connecting-link between that of the Whicham Valley and that of the Duddon Estuary. Water from this ice, held up between the two living streams, seems to have been responsible for the Millom-Park channels. In its escape northwards some of it fell into a temporary lake, held against the hillside between the ice-streams where they parted and flowed eastwards and westwards along the flanks of Millom Park. On the 400-foot contour there is a shelf-like feature, with sand and gravel, suggestive of a beach or delta-front.

Further withdrawal of the ice drained the lake, and the waters, following the marginal slope of the ice, cut channels at a lower level. Another lake was formed a little below the 300-foot contour, where there is a north-eastward facing delta of sand, gravel,¹ and boulders, extending for quite 300 yards, with a front 30 feet in height.

As we look up the hillside (down which they descend 100 feet in every quarter of a mile) the empty troughs appear to be suggestive of miniature valleys, lately occupied by miniature glaciers.

(b) The Gill-Scar Channel.—After this episode water began to accumulate in the lower part of the Whicham Valley, which was now being rapidly opened up by the retreat of the Whicham-Valley glacier. The more powerful stream of ice in the Duddon Estuary, however, still held the low ground north-east of Millom Park. The water rose to a height of about 200 feet, forming the Whicham Lake, which was impounded at the mouth of the valley by a lobe of the Irish-Sea ice.

Overflow took place in a southerly direction on the eastern side of Millom Park, near the margin of the Duddon ice, and the water fell into what was probably another lake in the mouth of the estuary north of Millom. The channel, cut by the overflowing waters under Gill Scar, is now a fine example of a dry rock-valley half a mile long. Commencing as a slight hollow, a little below the 200-foot contour, it rapidly develops into a V-shaped gash the floor of which crosses the 100-foot contour about a quarter of a mile from its head, the valley at that point exceeding 70 feet in depth. Lower down it is nearer 90. About half-way down there is a step in the floor where a valley enters upon the eastern side.

The Whicham Lake will be dealt with more fully in a subsequent paragraph (p. 441).

(c) Windy-Slack and Knott-Gill Channels.—These are good examples of steeply-descending dry rock-valleys, the gradients of which bear a direct relation to the gradients of the glaciers wherewith they were connected.

Windy Slack is typically V-shaped, and begins rather abruptly. It is over 50 feet deep, 500 yards or more long, and its floor descends 100 feet in 400 yards. It was cut in the volcanic

¹ Some pieces of Triassic sandstone were found here.

rocks when the western margin of the ice, west of the Duddon Valley, rested against the rising slope of Lathrigg at nearly 800 feet. A similar but smaller valley occurs in parallel sequence with Windy Slack about 200 yards farther east.

The head of the Knott-Gill Channel is about a mile to the south, and lies just below the 600-foot contour-line, that is to say, a little lower than the lower end of Windy Slack. It may, therefore, have been in operation at the same time as Windy Slack, the water crossing the gap between them by traversing the glacier that occupied the Black Beck valley.

The marginal channel takes a south-westerly trend across the south-eastern shoulder of Knott Hill. It is a V-shaped valley, 600 yards long, with a rather uneven floor descending about 150 feet, that is, at about the same rate as Windy Slack. It is excavated in volcanic rocks, but ends in boulder-clay on the lower ground. Near both its head and foot there is a little gravel (fig. 15, below).

At that time the Whicham Lake was probably in existence.

Fig. 15.—*The Knott-Gill marginal channel, looking north-north-eastwards.*

[This view shows the steep gradient common to the marginal channels which are associated with the steeply-descending inland glaciers.]

The ground on the west of the Duddon Valley north of Windy Slack was not examined in detail, but a dry valley was visible between the 500- and 600-foot contours on the eastern slope of Penn Hill, north of Logan Beck; and I have little doubt that others would be found in similar situations as far north as Seathwaite.

(3) Sand and Gravel of the Plain.

The coast-sections of sand and gravel which form so large a part of the plain have been already described (p. 416), and we have seen that these beds are to some extent stratified. Inland sections confirm this conclusion. The drift between Bootle and

Hycemoor is sandy, and the railway-cuttings south of Bootle, as also near Millom, show the presence of a great amount of sand and gravel with smaller interstratified beds of clay. Some 9 feet of stratified gravel has been exposed at Bootle Union Workhouse; and a section about 350 yards west of Far End also showed layers of red sand beneath gravel. Other sections occur near Kirksanton.

These deposits rest upon the Lower Boulder Clay, which rises from beneath them and climbs the rising flanks of Black Combe, or occupies the lower ground (as, for example, seaward of Silecroft and Millom) where the sands are absent (see fig. 2, p. 415).

Since, therefore, an almost continuous sequence of events has been traced from the time of maximum glaciation to the formation of the marginal channels, when the ice-front stood close to the hills, it is evident that the sands and gravels of the plain must have been formed at a later date.

The general level of the plain is rarely higher than 100 feet, although, at The Hawes, near Annaside Bank, it rises to 159 feet. It has been considerably dissected by post-Glacial denudation, which has had the effect of accentuating the original diversities of its surface.¹ Here and there small sheets of water, such as Barfield Tarn, a mile south of Bootle, lie in the hollow depressions (probably old kettle-holes).

Between Eskmeals and the Annas, south-west of Bootle and east of the railway, there is a long low-lying valley suggestive of an old marginal channel, now drained by streams flowing in both directions from a low watershed near Bootle Workhouse. In this neighbourhood are several other hollows and ridges, running north and south, which appear to be original features, slightly accentuated by denudation.

Taking everything into consideration, I am of opinion that the sands and gravels of the plain were accumulated during the period which followed upon the cutting of the lowest undoubted marginal channels, and that the water from the melting ice, fortified by that from Eskdale, etc., was more frequently spread out over a large area than concentrated in definite channels, because of the relatively low surface-gradient.

In the main, the material was deposited beyond the ice-limit, frequently in stratified layers beneath temporary sheets of water; but other parts were formed in a more irregular and tumultuous manner by torrential action. The deep hollows or kettle-holes are probably due to blocks of gravel-covered ice which, becoming detached from the ice-sheet, melted out and allowed their covering of drift to sink into the hollows thus formed.

A comparison may be made with the gravels of the northern side of Nunatak Fiord, Alaska, which form a series of benches altogether about a mile in width, the Fiord itself being only from

¹ Which would have been first toned down by the deposit of Upper Boulder-Clay.

1 to 2 miles wide. They were thus described by the late Prof. R. S. Tarr (U.S. Geol. Surv. Prof. Paper No. 64, 1909, pp. 128 & 129):—

‘The wave-cut cliff is from 75 to 100 feet in height and nearly vertical. The lower half consists of a rudely assorted till-like deposit, including horizontal bands of well-assorted materials; the upper half is well-stratified gravels. . . . There are layers of sand and gravel, with individual boulders of large size here and there, and with occasional beds of boulders. While most of the layers are gravel, there are also numerous beds of sand and, still more rarely, layers of clay. . . . The pebbles in the gravel layers are well rounded and varied in character, and include a large percentage of foreign fragments. No disturbance of the strata such as would have resulted from either ice-thrust or slumping was seen. These gravels attain great thickness, being revealed in some of the stream-cuts to a depth of more than 150 feet.’

‘All evidence that is obtainable points to the conclusion that the gravels of Nunatak Fiord are remnants of marginal accumulations. . . . That they are waterlaid is evident from their stratification; and that, to some extent, at least, they were deposited in standing water is proved by the large boulders scattered through the gravels, which are too large to have been brought by a glacial torrent, but might have been transported in icebergs. So they were probably accumulated, in part at least, in local marginal lakes. . . . It is inferred, therefore, that the gravel supply came largely from glacial streams issuing from the main ice-tongue, and that the dip of the layers towards the valley axis is due to the removal of a substratum of ice on which a thick blanket of gravel was deposited.

The drifts accumulated at this period would necessarily be of a varied character: for, on the comparatively flat ground upon which the ice was then resting, any slight disturbances of equilibrium in its mass would be translated into marginal oscillations, which would give rise to varying conditions of deposit of sediment.

The sands and gravels are not found everywhere: in some cases, no doubt, because the ground was still occupied by ice which afterwards withdrew quickly; in other cases, perhaps, because they were removed during a re-advance.

In this connexion it is interesting to note that the largest areas of Lower Boulder Clay, not covered by sand and gravel, occur near the mouth of Eskdale and along the coast southwards to Annaside, and on the plain south-west of Silecroft and south of Millom. We might conclude, therefore, that the ice-margin rested (at the period which we are considering, after the tongues of land-ice had parted from it) on the Lower Boulder Clay, where the gravels are generally absent, with convex lobes thrust out towards the mouth of Eskdale, the Whicham Valley, and the Duddon Estuary, and concave embayments, in which sands and gravels were accumulated, swinging westwards between these lobes.

Thus the conclusion, previously expressed (pp. 412 & 420), that the Irish-Sea ice invaded the mouths of the valleys, and in its retreat seemed to withdraw from them reluctantly, is borne out. This wave-like contour of the ice-margin will probably be found to have obtained at other points, both north of Eskdale and south of the Duddon Estuary.

Accumulations of sand and gravel were formed, not only within embayments in the ice-front, but also in the converse embayments of the land-surface invaded by the lobed ice-margin.

(4) The Whicham-Valley and Duddon-Estuary Lakes.

When the Whicham-Valley ice broke connexion with the retreating lobe of the Irish-Sea ice, the valley, as explained above (p. 437), became the site of a lake with an ice-dam at its lower end.

The valley and lake formed a convenient place into which the surplus material from, and moving along, the ice-front could be shot; and we consequently find that for more than a mile above Silecroft the valley was filled from side to side with fluvio-glacial deposits, ranging from clay and silt to sand and gravel, and boulder-beds (fig. 16, p. 442).

The deposits, still covering half a square mile between Silecroft and Whicham Hall, form a tract of typical hummocky ground, the higher parts of which fall from nearly 200 feet on the western side of the valley to 100 feet along its central line. On the eastern side they have been removed by the Whicham Beck, but some relics were found above the 100-foot contour on the eastern side of the intrusion at Nicle Wood.

Sections show that there is a great deal of red sand, which at times contains rolled lumps of red clay, or passes laterally into beds of clay. In the centre of the area a thin bed of fine loose sand overlay false-bedded sand dipping at 45° southwards. A neighbouring section in clear red sand showed a similar dip. A gravel-pit, a quarter of a mile south-south-east of Whicham Hall, is opened in a very roughly-stratified sandy and gravelly deposit of a morainic character, dipping on the whole in a south-south-westerly direction. It contains boulders which lie at all angles, as well as large lumps of red boulder-clay stuck full of stones. Boulders of granite and volcanic rock occur up to 18 inches in size, and also fairly large pieces of red sandstone, slate, and shale. Stratified sand and gravel, resting on Carboniferous Limestone, at the southern end of the valley has false-bedded layers dipping south-eastwards.

The floor of the Whicham Valley is covered by boulder-clay (p. 410), which also rises a little way up both sides. Thus the sand and gravels are flanked on each side by boulder-clay, and probably also rest upon it. In the part of the valley which was submerged the boulder-clay has been modified at the higher levels by denudation and the formation of terraces, and at the lower levels by deposit.

The terraces, or old beach-lines, which usually consist of flattish ledges, with sloping fronts, covered by slaty shingle, occur at various levels below the 200-foot contour, as shown on the accompanying map (fig. 16, p. 442). Near Whicham Hall there are three, the lowest being on the 100-foot contour and the highest at about 180 feet. The last-named can be traced, at intervals, round the northern end of the lake and some distance down the eastern side. The 100-foot terrace, when followed northwards, merges into the alluvium.

The deposits between the 180-foot and the 100-foot beach-lines consist of variegated (pale-grey, yellow, brown, and red) stony clay and loam full of slaty debris, many of the fragments being striated,

This deposit presents a characteristically patchy appearance in ploughed fields.

In the becksides, 600 yards south of Whicham Mill, a stony clay rests unevenly upon a deposit containing strips of red and chocolate-coloured laminated clay and warp. In other places 2 feet or more of red sandy clay is seen.

At levels below 100 feet, shingle, consisting of unweathered slate, is mixed in a heterogeneous way with weathered slate-débris and patches of red, purple, or greyish clay. The clay breaks up into small cubes, somewhat like the fine loam of a river-deposit.

Fig. 16.—Contour-map of the lower part of the Whicham Valley, illustrating the Glacial lake, on the scale of an inch to the mile (1 : 63,360).

At the north-eastern extremity of the lake, close to Seathwaite Bridge, between 150 and 180 feet O.D., there is a deposit, probably of a deltaic nature, formed by waters from glacier-tongues which lingered in the hollows on both sides of Baystone Bank. It is composed of boulders with interstratified beds, a foot or more in thickness, consisting of rapidly alternating layers of yellowish sand, silt, and red warp. The dip observed at one point was in a south-south-easterly direction. This deposit may, however, have been formed, at a slightly earlier date, in a temporary lake enclosed between the two above-mentioned ice-tongues when they were confluent.

Another fluvioglacial deposit at Sandholes Wood, about 500 yards from the Gill-Scar outflow (p. 437), is not quite so easily explained.

The greater part lies between 140 and 160 feet, but rises nearly up to the 200-foot level at its western end. A gravel-pit at the cross-roads at Sandholes Wood showed beds of stratified sand, gravel, and boulder-gravel. Some of the sandy bands were false-bedded, the dip of the thickest layer observed being to the east; others dip northwards.

The boulders are all Borrowdale rocks, with the exception of a few of pinkish quartz-porphry or granophyre. In the finer gravels there are a few granite-pebbles, and slate is common. Much of the sand is of Triassic origin, and contains rolled lumps of reddish clay (like that of Silecroft brickyard), pebbles of Triassic sandstone (maximum diameter = 3 inches), and pieces of marl.

I consider this deposit to be also of a torrential and deltaic nature, chiefly due to the re-arrangement of material formed on the slopes of Millom Park at a slightly higher level and at a slightly earlier date, before the opening of the Gill-Scar Channel. Some of the Triassic material, and perhaps also sand and small boulders, may have been floated to the spot by icebergs, and incorporated in the deposit when it was undergoing re-arrangement.

The floor of the Gill-Scar intake being somewhere near 170 feet, it is clear that the emptying of the lake below this level required another exit, which appears to have been furnished by the withdrawal of the ice from the mouth of the valley and the opening-up of a pathway for the escaping water (perhaps through the ice) at its southern end. The reversal of flow may account, in part at least, for the southerly and south-westerly dip observed in places in the uppermost layers of the sands and gravels (p. 441).

East of Nicle Wood there is a saddle, which might be taken for an abandoned outflow-channel cut in the hillside. The notch, however, seems to be a natural gap due to differential weathering, the Skiddaw Slate of Nicle Wood being stiffened by a small intrusion. The floor of the saddle is covered by boulder-clay.

A temporary check gave rise to the 100-foot beach-line, after which the lake-barrier seems to have consisted entirely of drift,¹ and the life of the lake depended upon the time required for the overflowing water to cut its narrow valley (now occupied by the Whicham Beck) down to the level of the lake-bottom (fig. 17, p. 444).

A series of similar mounds of fluvioglacial material occupies the low ground north of the outskirts of Millom, and extends northwards for about a mile. It occurs at Pannet Hill at 100 feet O.D., and at a little lower level near Beck Farm, where 6 feet of coarsely-bedded Triassic sand is covered by 8 feet or more of gravel containing boulders and patches of reddish clay. Granites, red sandstones, and shingly slate-fragments occur here, as well as the usual assemblage of volcanic rocks.

The sand which rises from the alluvium as a low hill at Millom Castle appears to be part of an outwash fan in front of the coarser

¹ These deposits were noticed by Mr. J. D. Kendall, who, however, ascribed to them a very different origin.

deposits to the south, and was probably formed as a delta in a lake held up by ice crossing the estuary-mouth. A pit shows over 8 feet of finely-laminated and slightly false-bedded sands and silts, containing small pebbles of granite and sandstone measuring up to 3 inches in greatest diameter. The coarse boulder-, sand-, and gravel-beds of variegated tints, exposed in a quarry near the vicarage at the mouth of the Gill-Scar channel, three-quarters of a mile north of Millom Castle, are of a different origin, and the sandy layers consist of other than Triassic material; they may, however, have been deposited in the same sheet of water.

In one of the top layers I found a small boulder of rotten biotite-granite, which may have come down the Gill-Scar Channel from the Whicham-Valley Lake.

The water accumulated in front of the ice crossing the Duddon Estuary must have escaped somewhere to the south along the coast-line of Furness, where signs of its passage may one day be found.

It would also be interesting to determine whether (as I suspect) the accumulations of sand and gravel in the mouth of Eskdale, the St. Bees Valley, and other valleys in the intervening tract of country, were deposited while the Irish-Sea ice was holding up extra-morainic lakes in these valleys.

Mellard Reade described Marine Drift [*sic*] in Eskdale and Miterdale¹ as occurring up to a height of 400 feet above sea-level, pebbles of St. Bees Sandstone being found

as high up as 320 feet. In Miterdale they are found 2 to 3 miles up the valley from their nearest outcrop,² and as much as 4 miles up Eskdale. (In the Whicham Valley they are more than 2 miles from its mouth.) If there were lakes in these valleys, some of their overflow waters may have taken a share in cutting the marginal channels north of Bootle.

¹ 'Eskdale Drift, & its Bearing on Glacial Geology' *Geol. Mag.* dec. 3, vol. x (1893) p. 19.

² *Ibid.* p. 14.

Fig. 17.—The mouth of the Whicham Valley seen from the west.

[The barrier of drift is seen behind the house on the left, the exit of Whicham Beck in the centre, and Niele Wood on the right.]

X. THE UPPER BOULDER CLAY.

The origin of the Upper Boulder Clay, which frequently forms the highest division of the drifts, presents a problem to which this district, so far as I have studied it, furnishes few definite clues.

It is usually red, of a more loamy texture than the Lower Clay, and often contains very few stones; yet at other times it is full of stones, and the Lower Clay, becoming loamy, resembles it in tint and texture, making it difficult, were the gravels absent, to separate the two.

If—as is highly probable—the Upper Clay is the result of a temporary re-advance of the ice, which had withdrawn itself for some distance from the present coast-line, it is just the type of clay that we might expect to find deposited on the sands and gravels: for it would be naturally composed chiefly of the upper part of the previously-formed Lower Clay, mixed with a certain amount of sand and gravel, incorporated when it mounted and overrode those deposits. A re-advance would imply a lowering of temperature and a possible hardening of the gravels by freezing. The ice would then easily override the latter, and deposit the material which it dragged up with it on the surface of the gravels as loamy Upper Boulder Clay.

If we require a precedent for the overriding of gravels by ice and the deposition of till and morainic matter upon them without destroying them, it is furnished by examples in Nunatak Fiord, Hidden Glacier Valley, and Russell Fiord in Alaska.¹ The surfaces of these gravels (up to 150 feet in thickness) are carved into a series of swinging, undulating, or dome-shaped curves, which terminate the layers of gravel, and are characteristic of ice-erosion. A layer of till, or hummocks and ridges of morainic material deposited during the period of overriding, covers much of the surface-area.

If the Upper Boulder Clay of the Black Combe district was formed in this manner, the advance of ice did not greatly disturb the sands and gravels, and seems to have spent itself before the base of the hills was reached.

XI. CORRIE-GLACIERS.

After the maximum glaciation, when the ice had abandoned the hill-tops for the low ground, small glaciers lingered in some of the upland valleys, occupying the sites of those which must have been initiated there in the early stages of glaciation. They may have again come into existence during the formation of the Upper Boulder Clay. Black Combe is a typical mountain-corrie, the floor of which hangs above that of Whitecombe. It was occupied by a corrie-glacier,

¹ R. S. Tarr, 'The Yakutat Bay Region, Alaska' U.S. Geol. Surv. Prof. Paper No. 64 (1909) pp. 126, 128, & 132.

which, when it had dwindled to a mere snow-slope, left a small moraine 250 yards from the screes at the head of the combe.

This moraine formerly held up a small lake, which finally drained away through a breach. A similar small lake-site, with a breached moraine below it, may be seen below the crags at the head of Stoupdale Beck.

XII. HANGING VALLEYS.

Glaciation of this area has given rise to discordance in grade between some of the main and tributary valleys. On the western slope of Black Combe all the small valleys are hanging. The upper parts of the streams are gently graded; but, when they reach the

Fig. 18.—*The Black Combe hanging valley and corrie, looking westwards.*

oversteepened slope of the mountain, they occupy narrow post-Glacial gorges, down which they cascade to the level of the drift-plain.

Black Combe, drained by Blackcombe Beck, hangs 200 feet above the valley of Whitecombe Beck (fig. 18, above).

The floor of the Whicham Valley and the mouths of most of its tributaries being drift-filled, it is difficult to say whether the rock-floors are at accordant grade with the main floor: this much, however, is certain—with the removal of drift from the lower parts of the tributary-valleys there is great activity near the headwaters. In Stoupdale Beck, about half a mile west of Baystone Reservoir, for example, there are some small, but very neat, incised meanders cut in grey slate.

XIII. GENERAL CONCLUSIONS.

(i) With the exception of the coastal drift-plain, the main features of the district had been developed before the advent of the Ice Age.

(ii) At the period of maximum glaciation, the Black Combe

district was completely swamped beneath an ice-sheet formed by the confluence of the Lake-District ice-cap and the Irish-Sea ice-sheet.

(iii) The Lake-District ice invaded the area from three main directions: (a) the Broughton Valley; (b) the Duddon Valley and high ground on the west; and (c) Eskdale.

(iv) The overmastering pressure of the Irish-Sea ice diverted the seaward flow of the Lake-District ice to the south or south-east, and in some cases forced it inland.

(v) The Lower Boulder Clay of the coastal-plain is the ground-moraine, chiefly of the Irish-Sea ice-sheet.

(vi) In the Lower Boulder Clay of the westward mountain-slopes there is evidence both of the interweaving of drifts of distant and strictly local origin, and of a certain amount of movement of ice inland.

(vii) Stages of withdrawal of the ice from the hills were marked by the occurrence of moraines, moraine-terraces, trails of boulders, and perched blocks.

(viii) Valleys, which are now for the most part either dry or occupied by insignificant streamlets, and do not accord with the pre-Glacial drainage-system of the district, represent channels subsequently cut by the marginal drainage of the shrinking glaciers or by the overflow waters from ice-dammed lakes.

(ix) On the granitic and volcanic tracts south of the mouth of Eskdale, the excavation of marginal channels followed upon a slight re-advance of the ice, which overrode gravels previously accumulated as a marginal outwash-fan.

(x) The sand and gravel of the plain was accumulated during the period which followed upon the cutting of the marginal channels upon its eastern border. The material was, in the main, deposited in embayments of the ice-margin, frequently beneath temporary sheets of water, but some parts were entangled with the melting edge of the Irish-Sea ice.

(xi) Sand and gravel were also accumulated at the extremities of lobes of ice thrust into the mouths of valleys, such as the Whicham Valley and Duddon Estuary.

(xii) The ice-lobes held up lakes in the lower ends of the valleys. The Whicham-Valley Lake at first drained into the Duddon Estuary by the Gill-Scar overflow, but afterwards through the obstructing barrier.

(xiii) The Upper Boulder Clay seems to be the result of a restricted re-advance of the Irish-Sea ice, which overrode the sands and gravels of the plain.

(xiv) The Lake-District ice, after the maximum glaciation, withdrew concurrently with the Irish-Sea ice, and corrie-glaciers lingered in sheltered combs at a late stage.

(xv) Certain hanging valleys are due to the oversteepening of hill-slopes, or overdeepening of main valleys by glacial action.

EXPLANATION OF PLATES XLI-XLIII.

PLATE XLI.

- Fig. 1. The Kinnmont-Beck Valley, east of Low Kinnmont, looking eastwards. The pre-Glacial granite valley was filled with Boulder Clay, which is now being removed and re-arranged as terraces by the stream. (See p. 422.)
2. The Kinnmont dry valley south of Welcome Nook, looking southwards. This view shows a broad marshy floor and a steep wall on the outer side of the bend. (See p. 425.)

PLATE XLII.

- Fig. 1. The Corney-Hall dry valley, looking eastwards. The view is from the bottom, looking up towards Corney Hall at the eastern end. In the background the Corney valley crosses at right angles. (See p. 426.)
2. The Near-Bank 'in-and-out' valley, looking northwards. Near Bank is the farm on the right of the observer: the granite-crag on the left is isolated. A small stream enters upon the right, and throws a delta across the valley. (See p. 426.)

PLATE XLIII.

Contour-map of the Black Combe district on the scale of 1 inch to the mile, or 1 : 63,360.

DISCUSSION.

Mr. G. BARROW remarked that the Author was dealing with an incident in a great campaign. England had been invaded on both sides by ice-sheets—one from the east, the other from the west, which had left traces of their course in the form of dry valleys cut by streams flowing at the margin of the ice. The Author had described the phenomena produced along successive margins of the western sheet, in the south-western portion of the Lake District; the speaker had noted a great gorge (Rudyard Gorge) cut by a marginal stream at the southern end of the Pennine Range. What was now wanted was a description of the valleys and ledges left by the ice in the great intervening area, on the western side of the Pennines.

Mr. G. W. LAMPLUGH said that, having some time ago traversed part of the area described, he could corroborate the Author's account of the general conditions of its glaciation. The movements of existing glaciers had proved to be so irregular, that it was unnecessary to expect much regularity of arrangement in the marginal channels.

The AUTHOR, in replying, thanked the President and Fellows for their kindly reception of his paper.

Quart. Journ. Geol. Soc. Vol. LXVIII, Pl. XLI.

Fig. 1.—*The Kinmont Beck Valley, east of Low Kinmont,
looking eastwards.*

B. S. photo.

Fig. 2.—*The Kinmont dry valley, south of Welcome Nook,
looking southwards.*

B. S. photo.

Quart. Journ. Geol. Soc. Vol. LXVIII, Pl. XLII.

Fig. 1.—*The Corney Hall dry valley, looking eastwards.*

B. S. photo.

Fig. 2.—*The Near Bank 'in-and-out' valley, looking northwards.*

B. S. photo.

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GENERAL MAP OF THE BLACKCOMBE DISTRICT *Illustrating the ice-movement during the maximum glaciation, and the occurrence of marginal channels formed during the retreat of the ice.*

- Indicates direction of ice-movement.
- " glacial striae.
- " *roches moutonnées* and smoothed rock-surfaces.
- " drainage-channels.
- " Do. Do. with one wall only.

Contour-lines are in red.
Scale: 1 inch = 1 Mile, or 1:63,360.