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THE GLACIATION OF THE BRADFORD AND KEIGHLEY DISTRICT.

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CONTENTS.

I.—INTRODUCTION.

The object of the paper is to attempt the correlation of the Glacial phenomena of the neighbourhood of Bradford and the adjoining portions of Airedale. The area covered

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extends from below Skipton to the western outskirts of Leeds, and is bounded by the Aire and Wharfe divide on the north, and by the Aire and Calder divide on the south.

The following is a brief *resumé* of the chief results obtained by previous observers in this district:—

In 1869 Taylor* described the gravel mounds occurring in the Aire valley, near Bingley, and concluded that they were formed during a "pluvial period," when the River Aire had a much greater volume than it has at present.

Macintosh† in 1871 mentioned the distribution of superficial deposits of boulder-clay from the north-west of Airedale to the east of Leeds, and remarked that the Carboniferous Limestone pebbles and boulders contained in the clay are very abundant in the north-west, but decrease in numbers south-eastwards. Although leaning towards deposition in water as an explanation of the facts, he very carefully noted the difficulty of separating the various deposits—clay, sand, and gravel—into distinct strata.

In 1872 the following important generalisations were arrived at by Mr. Dakyns.‡ The ridge between Airedale and Calderdale separates the former drift-covered area from the latter driftless one. Wherever two large valleys join there is a great pile of drift heaped up between them. Where a barrier of rock crosses the valley the drift is piled up in mounds against and over the rock, and above such a barrier there is a wide spread of alluvium. The nature of the drift, and the fact that it is generally found entirely on the east and south-east sides of hills, indicate that the direction of ice-movement was generally from west and north-west to east and south-east.

Besides water-worn gravels the occurrence of "scratched gravels" was recognised, and their passage into water-worn gravels noted.

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* Quart. Journ. Geol. Soc., vol. xxv., 1869, p. 57.

† Proc. Yorks. Geol. and Polyt. Soc., vol. v., 1871, p. 103.

‡ Quart. Journ. Geol. Soc., vol. xxviii., 1872, p. 382.

The same year Mr. R. H. Tiddeman* adduced evidence from striæ and drift that the Pennine watershed west of Skipton had been over-ridden by an ice-sheet from the west.

In 1873 Russell† shortly described the character of the boulder-clay and gravels of the Bradford district. He considered that the gravel ridges extending from Burley Moor to Hawkesworth were eskers.

In 1875 the Survey Memoir on the Geology of the Burnley Coalfield‡ described the distribution of drift on the western flanks of the Pennines, and mentioned the occurrence of a driftless area east of Boulsworth and Black Hambledon. To the north of Combe Hill drift was traced continuously across the low portion of the main Pennine ridge. In the gap between Combe and Crow Hills no drift was found on the watershed (1,125 feet), the first traces being met with 1½ miles down the eastern side.

Green and Russell in the "Geology of the Yorkshire Coalfield" (Survey Memoir, 1878), defined the margin of the drift-covered area as following the water-parting between the Aire and Calder as far as the head of the valley of the Bradford beck, and then passing in a general easterly direction through Leeds. Details of numerous occurrences of the superficial deposits in Airedale are given.

In 1887 Prof. H. Carvill Lewis§ stated that the Airedale Glacier held up two lakes on its southern margin. One of these occupied the valley of the Bradford Beck, the other the Worth Valley.

In the "Report of the Director-General of the Geological Survey for 1895," Mr. Tiddeman was credited with remarking that gravel mounds occur in Airedale at all elevations from 1,150 feet to the valley bottoms, and therefore

* Quart. Journ. Geol. Soc., vol. xxviii., 1872, p. 471.

† Brit. Assoc. Report (Bradford), 1873, Trans. of Sections, p. 88.

‡ London, 1875.

§ Brit. Assoc. Report (Manchester), 1887; also "Notes on the Glacial Geology of Great Britain and Ireland," London, 1894.

they cannot be connected with normal stream action. The ice-striæ on the high hills indicate an ice-movement across the deep tributary valleys of the Aire.

Mr. J. E. Wilson published in 1900 the results of an investigation undertaken to verify the statement by Prof. Carvill Lewis given above. He adduced evidence to show that there was a lake in the Bradford basin having its outlet at Laisterdyke. Streams flowed into this lake, *vid* Stream Head Col and Chellow Dean; the Leventhorpe beds were said to be the delta of the former stream, and the significance of the fact that this delta was at the same altitude as the Laisterdyke outlet was pointed out. Chellow Dean and the gorge at Stream Head Col were regarded as the result of the overflow of a lake in the Worth and Harden drainage areas. The deep notch at Sugden End, near Haworth, was considered to be the outlet of the Worth Valley lake at one period.*

Much of the following paper was presented by us as a brief summary to the Bradford Meeting of the British Association (1900).†

II.—General View of the Surface Features of the Area.

The portion of Airedale between Skipton and Leeds is excavated wholly in rocks of Carboniferous age. In the north-west, around Skipton, are to be found the rocks of the Carboniferous Limestone series. These are followed about a mile below Skipton by the Millstone Grits, the outcrop of which occupies the largest part of the area under description. In the south-east the Lower Coal Measures—overlying the Millstone Grits—extend from the hills east of Oxenhope to Cottingley, and thence along the southern side of Airedale to Kirkstall, beyond which they occupy both sides of the dale. Outliers of Lower Coal Measures on Millstone Grit occur between Yeadon and Horsforth, on Hope Hill, near Baildon, and at the head of the Glusburn

* Brit. Assoc. Report (Bradford), 1900, p. 755.

† Brit. Assoc. Report (Bradford), 1900, p. 756.

Valley. The alternation of the harder beds of grit, sandstone, and gannister, with the softer bands of shale, is the cause of the terraced features which the hills present. The rocks are intersected by numerous faults.

The general trend of Airedale in this district is from north-west to south-east. Actually, the valley makes a number of roughly rectangular bends, receiving a large tributary valley from the south side at each southern convexity, viz., the Glusburn Valley at Kildwick, the Worth Valley at Keighley, the Harden Valley at Bingley, and the Bradford Valley at Shipley. The Worth River itself receives two large tributaries, viz., Newsholme Dean Beck on the left at Keighley, and Bridgehouse Beck on the right at Oakworth.

The watershed on the south-west reaches an altitude of 1,554 feet on Crow Hill. Northwards its altitude falls below 1,125 feet at the head of the Worth Valley, reaches 1,454 feet on Combe Hill, and sinks again in a broad depression at the head of the Glusburn Valley to below 900 feet. A further rise takes place on Thornton Moor (Thornton-in-Craven), but does not exceed 1,300 feet. To the south-east of Crow Hill the divide gradually decreases in altitude, being about 700 feet south of Bradford, and falling below 450 feet south of Leeds.

The watershed between the basins of the Aire and the Wharfe reaches an altitude of 1,323 feet on Rumbles Moor. To the north of Silsden it falls to 770 feet and in the broad transverse valley east of Rumbles Moor to 450 feet. Beyond this transverse valley it rises to 925 feet on Otley Chevin, and gradually falls again eastwards.

III.—The Glacial Deposits.

The glacial deposits may be conveniently divided for the purpose of description into :—

i. Boulder-clay or till.
ii. Sand and gravel.
iii. Unstratified gravelly or clayey material more or less intermediate in character between i. and ii.

i.—THE BOULDER-CLAY OR TILL.

The boulder-clay is a tough, bluish, unstratified clay containing numerous striated and moulded stones lying in all positions, and scattered irregularly through the clay. Its surface is smooth or slightly undulating, and the minor rock features are more or less hidden and levelled over by it. Though it occasionally forms a rude terrace-like feature, boulder-clay is rarely arranged into drumlins in this district, as it is in the open country to the north-west of Skipton. A few examples, however, have been noted, the best of which occur in the transverse valley east of Rumbles Moor, between Burley Wood Head and Guiseley. The boulder-clay usually forms a thick deposit, covering the floors of the valleys and thinning out up the hill slopes. As pointed out by previous observers, it occurs most abundantly on those hill-slopes which face south or south-east, i.e., it occurs on the lee sides of hills with reference to the direction of the flow of the ice.*

The stones in the clay are chiefly of Carboniferous rocks, and include limestone, chert, grit, sandstone, gannister, shale, coal, and ironstone nodules. The stones are generally more rounded the further they are found from their parent outcrop. Amongst the *boulders of Carboniferous Limestone* are found all the varieties which occur in the vicinity of Upper Airedale, viz., the white encrinital and compact blue varieties, the fossiliferous limestone of the "reef-knolls" of Craven, and the black Pendleside limestone. The shale, which occurs in the Carboniferous Limestone series has also been recognised in striated fragments in the boulder-clay. The limestone boulders may have their angles and edges rounded off, presenting a bruised and battered appearance, or they may be rounded and striated in a direction parallel to their long axes. They are most abundant in the till near Skipton, and become fewer in number and generally smaller in size as we proceed down the main valley, and as we approach the periphery of the drift-covered area from the main valley. Locally, however, the distribution of limestone boulders is very irregular.

* Dakyns, Quart. Journ. Geol. Soc., vol. xxviii., p. 382, 1872.

Boulders of *Millstone Grit* become abundant after entering upon the Millstone Grit outcrop to the south of Skipton, and they frequently attain a large size (seven feet or more in length). Large boulders of Grit are scattered about the Coal Measure hills to the north and east of Bradford. A peculiar compact siliceous rock, locally known as "*blue-stone*," crops out beneath the Rough Rock around the head of the Worth Valley, to which district it appears to be limited. Pebbles of this rock have been found in the drift in one or two places on the south side of Airedale and south-east of the outcrop of the stratum. Scratches are more often noticed on gannister boulders than on boulders of grit and sandstone, which do not appear to have received or retained them readily.

Pieces of *coal* and *ironstone nodules*, which are chiefly derived from the Coal Measures, are found in the till on the south and east sides of the Bradford basin.

Fragments of *cleaved green slate* and pebbles of *greywacke grit* have occasionally been met with. Two boulders of cleaved slate were found in the boulder-clay on the northern slope of Combe Hill at an altitude of 1,200 feet above O.D., and several other occurrences are noted in Section V. These rocks can be matched in the Silurian grits and slates outcropping on the Malham Moors at the head of Airedale and around Horton-in-Ribblesdale. Similar grits and slates were pointed out to us in the drift mounds at Bingley by Mr. E. E. Gregory, and Dr. Monckman has recently recorded "Silurian grits" from the boulder-clay behind Grange Road, Bradford.*

The above-mentioned facts serve to confirm the conclusion arrived at by previous observers, that the distribution of boulders indicates a general and regular south-easterly movement of the transporting agent in Airedale.

Boulders of *igneous rocks* have only rarely been found. Russell recorded "taking a few pebbles of trap and ash rocks as far up towards the watershed between the Aire and Calder [south of Bradford] as Rooley and Great Horton, and [took]

* "The Glacial Geology of Bradford and the Evidence obtained from Recent Excavations of a Limestone Track on the South Side of the Valley." By James Monckman, D.Sc., Proc. Yorks. Geol. and Polyt. Soc., vol. xiv., p. 157, 1901.

one block of coarse granite out of the drift clay on the east side of Bowling Lane, between Bowling House and the Oaks."*

Gibbins reported "at the N.W. of Bradford a few whinstone boulders, similar to those of Scaw Fell, Cumberland, containing small garnets."†

Prof. Carvill Lewis also records the find of "a piece of granite, six inches long, on the north side of Haworth Moor."‡

A boulder of andesite of a Lake District type was found in the excavation for the foundations of Hodgson's Power-loom Works, just north of Frizinghall Station.

It is well known that Lake District and Scottish rocks occur in the drifts to the south-west of a line stretching from Morecambe Bay by way of Longridge Fell to Burnley,§ but a few Lake District erratics have been found to the north-east of this line. Mr. J. H. Howarth|| has recorded a boulder of Borrowdale andesite from the Bolland Knotts, and Mr. A. Wilmore** has noted the presence of Lake District rocks near Trawden and Wycoller, which lie to the west of Combe Hill and Crow Hill.

More recently Mr. E. E. Gregory†† has recorded a boulder of Borrowdale ash from Far Slippery Ford, four miles west of Keighley.

It would appear therefore that the few Lake District erratics which have been found in Airedale have been transported across the low part of the Pennine divide north of Crow Hill and have been carried down the south-west side of Airedale.

The *matrix of the boulder-clay* varies more or less with the characters of the "solid" rock on which it rests, and of the

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* Brit. Assoc. Report (Bradford), 1873, p. 88.

† Report of Erratic Blocks Committee, Brit. Assoc. Report (Bristol). 1875, p. 91.

‡ "The Glacial Geology of Great Britain and Ireland," 1894, p. 237,

§ R. H. Tiddeman. "The Evidence for the Ice-sheet in North Lancashire." Q.J.G.S., vol. xxviii., 1872, p. 471. P. F. Kendall, in Wright's "Man and the Glacial Period," London, 1893, p. 146.

|| Erratic Blocks Committee, Brit. Assoc. Report, 1896, p. 372.

** "The Glacial Geology of Burnley and District." Burnley Literary and Scientific Society. Transactions, vol. xv., p. 58 (publ. 1900).

†† Erratic Blocks Committee, Brit. Assoc. Report (Southport), 1903, p. 231.

rock which lies to the north-west of it. At Skipton it is commonly a very tough, dark-blue clay, weathering at the top to a brownish colour. In the Coal Measure and Millstone Grit areas the blue boulder-clay is covered by a variable thickness of yellow boulder-clay, the junction being very irregular. In most sections the blue clay merges gradually upwards into the yellow clay, but sometimes the passage from one to the other is very rapid.

At the Thornbury Brickworks, on the eastern outskirts of Bradford, there is a cutting about 60 feet deep in boulder-clay. The upper ten feet consist of jointed yellow clay with boulders, which rests on tough blue clay, the junction plane being irregular. The difference in colour between the yellow clay above and the blue clay below is most marked, and yet, when the junction was examined, lenticular beds of sand were found to pass quite undisturbed across the junction. The upper part of one lenticle was in yellow clay, and the lower part of the same in the underlying blue clay. It is impossible to conceive that in this case the yellow clay can be anything but the blue clay altered in appearance by weathering subsequent to its deposition. The junction cannot mark a break in the accumulation of the two clays.

In January, 1900, the cuttings on the Midland Railway north of Bingley were being widened, and blue boulder-clay was exposed. Three months later the same sections, on which the marks of the workmen's tools were still visible, were found to have weathered to the depth of an inch from the surface to a yellowish-brown colour.

The boulder contents of the two kinds of clay, with the exception of limestone boulders, are identical. The few limestones that have been observed in the yellow clay almost always have corroded surfaces, and branching masses of *Syringopora* and *Lithostrotion* from which all the calcareous matrix has been removed have been found in it. These facts show that the yellow clay has undergone partial or entire decalcification by percolating waters, and the yellow colour of the clay is doubtless due to the oxidation of the iron contained in it.

The boulder-clay generally becomes thinner and more sandy in the upper parts of the tributary valleys towards the main

watershed on either side of the dale. As might be expected, it is then weathered completely through to a yellowish or, where beneath the peat, to a greyish colour.

Shales, particularly those of the Coal Measures in a driftless area, often weather at the surface to a fine yellow clay, which is to be distinguished from the weathered boulder-clay. The former may be seen passing down into rotten shale. It is of a buttery consistency when wet, is not gritty to the touch, and, if it contains any stones, these are quite angular and local in origin.

ii.—SANDS AND GRAVELS.

The stratified sands and gravels, though covering a much smaller area than the boulder-clay, are locally developed in thick masses. They attain their greatest development in the mounds and terrace-like features of the main valley. Isolated mounds and patches also occur on the hills, and water-worn gravels form fan-shaped accumulations at the mouths of some of the dry valleys which will be described below. Current-bedding is observable in almost every section. The pebbles of the gravels are derived from the same rocks as the boulders in the boulder-clay, and the general distribution of the various kinds is similar. The pebbles are generally well-rounded and water-worn. The sands and gravels usually overlie the boulder-clay, but are sometimes found to underlie or interdigitate with that deposit. There is, however, no persistent "middle sand and gravel" separating a lower from an upper boulder-clay, such as has been recognised in other areas.

iii.—GRAVELLY OR CLAYEY DRIFT MORE OR LESS INTERMEDIATE IN STRUCTURE BETWEEN i. AND ii.

A third kind of drift, intimately associated with the boulder-clay and the glacial gravels, consists of a confused mass of boulders and stones with a sandy or clayey matrix, which varies in amount from point to point. It is not always easily separated from either the gravels or the boulder-clay, and in fact it seems to pass in different sections into both these deposits. The stones are of similar kinds to those found in the boulder-clay. They are subangular or rounded, and are very variable in size.

Some of the boulders are striated, and this drift probably includes the "scratched gravels" of authors. It is found almost exclusively to form mounds and moundy features, which are morainic in origin, and it might be styled "morainic drift."

Moraines.—Lateral moraines are found on the hills, and terminal moraines of retrocession occur in the main valley. The latter are found at Tong Park, east of Baildon; at Nab Wood, between Saltaire and Bingley; and at Bingley.

The Tong Park moraine consists of mounds, chiefly of gravel and fine sand. They extend along the floor of the valley on the north-west side of the Aire for about half a mile. "Kettle-holes" are a common feature in the moraine.

The moraine at Nab Wood, three-quarters of a mile west of Saltaire, is probably the finest in the district. It forms a concentric mound, stretching across the valley, with a steep concave slope 60 feet high facing up stream. The best section is at an old quarry 100 yards east of the "Seven Arches." Here, coarse gravelly drift, sometimes over 20 feet thick, rests on the Millstone Grit. The boulders are subangular or rounded, and are commonly between five inches and one foot in length. There is generally a clayey or loamy matrix, but hardly any trace of stratification. The surface of the moraine is irregular and moundy, and is strewn with large blocks of grit.

Above the moraine is a stretch of alluvium, across which the river meanders. On reaching the moraine the river doubles back for a quarter of a mile, and escapes by a gorge cut through Millstone Grit at the northern end of the moraine. This is a very clear case of the so-called post-glacial diversion. It is very probable, however, that the gap had been opened and cut down to some extent before the ice-front had actually left the moraine.

Bingley stands on a group of drift mounds which choke up the valley for over a mile. The river flows through a deep and narrow channel cut along the south-west margin of the mounds. Sections opened for laying drains near Myrtle Park showed a very coarse boulder drift, rarely with a clayey matrix. The top six feet of the deposit had been turned over, and the limestone boulders picked out for lime-burning. The mounds

to the north of the town consist partly of gravel and partly of boulder-clay. The sections exposed in the widening of the railway line from the pointsman's box near the Parish Church to the Skipton road bridge showed hard blue boulder-clay passing upwards into yellow clay. Pebbles and boulders of limestone, generally striated, are abundant in the blue clay, but do not occur in the top three feet of the yellow clay. The hollows between the cuttings are floored with peat, which was over five feet thick, and contained remains of the oak near its upper surface. The cutting to the north-west of the bridge exposed a very stony blue clay passing upwards into yellow clay. The widening of the cutting below Marley Hall showed current-bedded sand and loam lying upon and banked around a mass of coarse gravel.

It has been suggested* that the terraces which lie on the flanks of the valley above Bingley may have been formed in a lake caused by the obstruction of the valley by the Bingley moraine. The altitude of the terrace is about 295 feet above O.D.

The Nab Wood and Bingley moraines are almost connected by a line of gravel mounds, along which the railway runs. Recent excavations have exposed 35 feet of coarse gravel without reaching the base of the deposit. The gravel consists of pebbles of Carboniferous grit, sandstone, and limestone, with a small admixture of Silurian grits, generally embedded in a matrix of sharp sand. The current-bedding generally dips to the east, whilst flat pebbles are tilted up so as to dip to the west, showing that the current of water which deposited the gravel came from the latter direction. At the sides of the mounds the bedding often conforms to the slope of the surface. The gravel ridge in many points resembles an esker, and it was probably formed by a sub-glacial stream of water in a tunnel in the glacier, perhaps at the time when the Nab Wood moraine was being accumulated.

A shorter but serpentine gravel ridge situated on the north side of the canal bank, between Shipley and Saltaire, may have had a similar origin. A pit opened in the middle of the mound

* Geology of Yorkshire Coalfield, p. 783.

shows current-bedded sand and gravel overlaid by coarse boulder gravel. The boulders are usually less than a foot long, though a few are nearly three feet in length. The coarse gravel cases in the sand and fine gravel, so that the section appears to be "arch-bedded." The stones in the gravel are water-worn and fairly well rounded. They consist of grit, sandstone, gannister, and limestone, with pieces of shale and ironstone nodules.

Lateral moraines trending from N.W. to S.E., or from W. to E. occur at several places on the hills on both sides of the Aire.

On Hallas Rough Park, about one mile S.S.W. of Cullingworth Station, a series of low drift mounds runs in an almost west to east direction. A section in a gravel pit near the eastern end of the mounds shows strongly current-bedded gravel and stratified sand interdigitating with irregular lenticles of bluish boulder-clay. At the top of the pit is a grit boulder over 3½ feet long, striated in the direction of its long axis from N. 40° W. to S. 40° E. These mounds lie almost at the upper limit of the boulder-clay, and were probably deposited at the edge of the ice about the period of its maximum extension.

A large mound on the east side of Denholme Station consists of unstratified gravelly drift. The boulders are mostly subangular, and are of all sizes up to three feet in length. They are chiefly composed of grit and shaley sandstone, mixed with bits of shale and sand. The mound on the other side of the station appears to consist of finer and more water-worn material resting on shale. The mounds seem to mark the limit of the drift in the Harden Valley, and are probably morainic in origin.

At Nook, nearly two miles W.N.W. of Oakworth Station, a small crescentic mound with its concave side turned towards the north-east is cut through by Newsholme Beck. It consists of very stony clay and was probably formed at the edge of the ice at some stationary period during the general retreat of the glacier. The altitude is 1,025 feet above O.D.

A little north of Cowloughton Dam, one mile south of Ickornshaw (Glusburn Valley), and at an altitude of 1,100 feet above O.D., unstratified gravelly drift is piled up into a large

mound, which has been worked for the limestone boulders which it contains. Near the old limekiln there are several large masses of unstratified gravel cemented by calcite into a hard conglomerate. The majority of the pebbles are of limestone, mixed with others of grit, sandstone, and shale. From this point a ridge of gravelly drift runs in a north-westerly direction towards Pad Cote, and a low ridge of clayey drift trends eastwards for nearly half a mile to Andrew Hill. Here a small stream section exposes three to four feet of yellowish sandy clay, containing rounded boulders of limestone, grit, gannister, shale, chert, calcite, and barytes. Boulders of grit and gannister lie about upon the surface of the mound. The whole ridge is probably morainic in origin, and marks the edge of the ice at a period during its retreat.

At the western end of Rumbles Moor, on the north side of Airedale, mounds of clayey drift occur at an altitude of 1,200 feet, and a low ridge crosses the Keighley and Ilkley road about $\frac{1}{4}$ mile W.S.W. of the Keighley Gate. These mounds were probably formed in the angle between the combined Airedale and Wharfedale ice-sheet, where it split against the western shoulder of Rumbles Moor.

Probably the most remarkable moraine in the district is that which begins at Lanshaw Delves, at the north-east corner of Rumbles Moor. It runs in a direction W. 12° N.—E. 12° S. for three-quarters of a mile, and then, turning towards the south-east, is traceable in a series of detached mounds which cross the head of Coldstone and Carr Becks, and run towards Craven Hall Hill. Up to this point the moraine is situated on the Wharfedale side of the Wharfe-Aire divide, but it now crosses the watershed and runs in a south-south-easterly direction to the reservoir near Reva Side. Beyond the reservoir the moraine is continued in a south-easterly direction to near Hawksworth. Isolated mounds situated opposite Hawksworth Hall continue the same line, and are known as Birkin Hill and Greenhouse Hill. Though generally a single ridge between 10 and 20 feet high, there are two, and sometimes three, parallel ridges on the moor edge above the reservoir. The moraine commences at an elevation of 1,175 feet at Lanshaw Delves, and is traceable

for four miles, gradually decreasing in altitude to 575 feet near Hawksworth. Along much of its course it has been dug into and turned over for the limestone boulders which it contained, but an almost undisturbed section can be seen on the north side of the reservoir, near Reva. Here it is formed of a sandy clay, containing numerous boulders of grit, limestone, and gannister scattered through it. The limestone boulders are usually rounded and striated, whilst those of grit and sandstone are sometimes quite angular and are seldom scratched.

Although the material exposed in the above section might be called a boulder-clay, it is not a typical till. Other parts of the moraine are more gravelly, and the mounds have been compared to an esker by previous observers. The above section, however, shows that this drift ridge is not an esker.

Two small drift mounds near Green Gates, on Ilkley Moor, connect Lanshaw Delves with the morainic mounds at the west end of the moor.

The relation of the till to this moraine is of some interest. At Lanshaw Delves the moraine seems to mark the upper limit of the drift on the south side of Wharfedale. No boulder-clay or gravel has been found south of the moraine between it and the watershed, though there is nothing in the shape of the ground to prevent such accumulation. Shortly after crossing the watershed, where the altitude is less than 1,000 feet above O.D., boulder-clay occurs indifferently on both sides of the moraine. It will be seen from the contoured map that the broad transverse valley east of Rumbles Moor opens widely towards the upper part of Wharfedale, but its junction with Airedale is somewhat constricted and points down that dale. The till on its western slopes is arranged in long narrow drumlins with smooth rounded contours. They run obliquely down the slope of the ground in a south-easterly direction, but curve round towards the east at their lower ends. It is thus evident that the Wharfedale ice pushed into the transverse valley to beyond Guiseley. It reached a height of at least 700 feet on the hills east of Guiseley, where a curved morainic ridge concave towards the west runs from West Carlton in a south-easterly direction for three-quarters of a mile. The western edge of this lobe of ice was marked by

the moraine, which stretched from Lanshaw Delves to Hawksworth. The Wharfedale ice thus overtopped the Aire-Wharfe divide north of Hawksworth, where it sinks below the 1,000 foot contour, and laid down its moraine along the slope of one of the tributary valleys of the Aire. This unexpected result shows that the Airedale glacier had begun to retreat whilst the Wharfedale ice was still at or near its maximum extension. The presence of the relatively high ground of Bingley Moor and Hope Hill, situated immediately to the west, must have assisted in fending off the Airedale ice from the Hawksworth ridge.

IV.—The Striated Rock-Surfaces.

The striated rock-surfaces, which have been found in this district, are with one exception on beds of grit. A thick bed of gannister provides the other example. Only the hard, compact rocks are capable of being well striated; the soft rocks, and the surfaces of hard rocks with many cracks in them, are simply ploughed up and smashed by the passage over them of a mass of ice containing stones. A section was observed at Stone Hall Hill, Eccleshill, where beds of shaley sandstone were covered by boulder-clay 9 feet thick. The upper surface of the sandstone was smashed, and the layers were pulled over in the direction of ice movement, viz., towards the E.S.E. Boulders and clay were forced into the crevices of the shattered sandstone. The soft nature of some, and the rubbly nature of other of the rocks of the Millstone Grit and Coal Measure series has thus led to a comparative scarcity of striated surfaces.

Striæ have generally been found in places where the rock is now, or has been until recently, covered with boulder-clay. The action of the weather soon obliterates any scratches which may exist on exposed surfaces of sandstone and felspathic grits.

Most of the striated surfaces are irregular. The consistent smoothing of the northerly or north-westerly facing sides of any prominences, whilst the south-easterly sides are left jagged and rough, affords the clearest evidence of a general ice movement from north-west to south-east.

It will be noticed that where the striated surfaces occur high up on the sides or on the tops of the hills, the direction

taken by the striæ is consistently from north-west to south-east, but that when they are found on the bottom or lower slopes of a valley, their direction more nearly conforms with the trend of the particular part of the valley in which they occur. A greater freedom of movement would be expected in the upper layers of a glacier than in the lower layers, which must mould themselves to the inequalities of the glacier-bed. Hence the high level striæ more truly represent the direction of the general ice movement than the others.

Several cases were noted where the scratches on large undisturbed boulders were in the same direction as those on the neighbouring rock-surface.

DETAILS OF STRIATED ROCK-SURFACES.

(1) The surface of the Rough Rock exposed in the small quarries and on the roadside above Long Lee, one mile south-east of Keighley, is striated in several places.* The striæ vary from fine scratches to broad grooves more than a yard long, and their direction is from N. 45° W. to S. 45° E., a few crossing them from N. 65° W. The surfaces are not always plane, and the various prominences are striated on their north-west sides, whilst their south-east sides are rough. Each of the quartz pebbles on the surface of the grit is polished and finely striated on its top and north-west side. In one or two cases the general surface is not level, but dips northwards at angles varying up to 16°, so that the material which produced the grooves must have been dragged obliquely up the slope of the surfaces. Their altitude varies from 750 feet to 825 feet above O.D.

(2) About three-quarters of a mile nearer Harden, and on the east side of the road, smoothed rock-surfaces may be seen grooved from N. 35° W. to S. 35° E.

(3) The grit exposed in the cutting on the Great Northern Railway, half way between Cullingworth and Wilsden Stations, is striated from N. 50° W. to S. 50° E. The north-westerly sides of the inequalities of the surface are rather more deeply and abundantly grooved.

* Indicated on the Geological Survey Map (1 inch 92, S.E.).

(4) In a quarry on the north side of Crag Lane, Windhill Crag End, Shipley, well-marked parallel striæ run from N. 35° W. to S. 35° E. The larger pebbles of quartz are covered with numerous close-set and fine scratches. The north end of each pebble is rounded and scratched, but the south end is left rough. Some of the pebbles, when hammered out, were found to have been so worn down that they were represented only by a thin lens of quartz.

(5) In the quarry between Midgeley Wood and Baildon Green, to the north of Shipley, the top of a thick substratum of gannister is of a montonnée character, well smoothed, and with well-marked though not very numerous striæ.* Three observations taken at distances of about ten yards apart gave for their direction, (1) from N. 90° W., (2) from N. 80° W., (3) from N. 77° W. The gannister is covered by a bed of clayey gravel up to four feet in thickness, which is in turn overlaid by 10-15 feet of yellowish boulder-clay.

(6) In the recent excavations west of Apperley Bridge Station, the top of the grit in the cutting was found to be striated from N. 25° W. to S. 25° E. Knobs of rock projected above the general level of the surface, and round these the striæ were deflected as much as 30°. On two large undisturbed boulders in the gravelly clay with limestone which covered the striated surface, scratches were observed running from N. 25° W. to S. 25° E.

(7) The floor of the pit opened within the enclosure of the Weecher Reservoir, near Fawcather, is composed of ferruginous sandstone, which is striated from N. 55° W. to S. 55° E. The striæ are numerous, and may be seen covering many square yards of the floor of the pit. They are also exposed in the bed of a small stream a little to the west. The surface is slightly uneven, and it is the north-west sides of the prominences which are striated. The scratches can be traced under the yellowish boulder-clay, which is about eight feet thick, and contains rounded and subangular boulders of sandstone, grit, gannister, and limestone.

* Recorded together with the preceding set in the *Glacialists' Magazine*, vol. v., p. 124, 1897.

(8) About 350 yards north-west of Horncliffe House, on Bingley Moor and beside the footpath, a plane and smoothed surface of grit is striated from N. 55° W. to S. 55° E. The altitude is 1,080 feet above O.D.

(9) At the corner of Morton Bank Lane, near High Wood Head (West Morton), a small surface of grit is exposed. The quartz grains are worn down smooth, and fine striæ groove the surface from N. 45° W. to S. 45° E.

(10) Mr. E. E. Gregory has kindly furnished us with details of a striated surface observed by him on Farnhill Moor, 200 yards S.E. of the Jubilee Tower. "The striæ show that the glacial material, which caused the groovings, has come from a point about 30° to the west of north. The whole of the rock surface for about a quarter of a mile to the north-east bears evidence of a similar condition." The altitude is 725 feet above O.D.

V.—The Distribution of the Drift.

The following notes on the distribution of the drift commence in the north-west and proceed down Airedale, taking first the south side and then the north side of the dale. The floor and lower slopes of the *Glusburn Valley* are covered with dark, bluish boulder-clay, weathering to a yellow colour and containing many striated boulders, a high proportion of which are of limestone. Behind Malsis Hall about 15 feet of bluish-grey boulder-clay, weathering to a yellow colour on the surface, overlies a high cliff of shale. The shale for a vertical distance of 12 feet beneath the boulder-clay is crumpled up and its bedding destroyed. Probably in this instance its position on the rim of a deep valley towards which the ice was moving has facilitated the shearing of the shale.

Good sections of the boulder-clay full of limestone boulders are exposed in the beck near Ickornshaw. It is often 100 feet in thickness without its base being exposed. The boulder-clay is continuous across the low part of the watershed with that on the western side of the Pennine axis.* Proceeding southwards,

* Geology of the Burnley Coalfield (Survey Memoir), p. 137, 1875.

rather sandy, greyish boulder-clay is found to spread up the northern slopes of Combe Hill to over 1,350 feet. The mounds near Cowloughton have been mentioned already (p. 205). On the summit of Combe Hill the surface is covered by angular débris of the underlying grits, and a search failed to reveal any drift-pebbles. No boulder-clay was found on the southern and south-eastern slopes of the hill, though had the hill been overridden by the ice, one would expect some boulder-clay to be preserved there.

On the western side of the col, between Combe and Crow Hills, a thick deposit of stony boulder-clay reaches up to within 50 feet of the watershed (1,120 feet). Southwards, on the western flanks of Boulsworth, the drift ranges again almost up to 1,400 feet. On the eastern side of Combe Hill the upper limit of the drift sinks into the Worth Valley and then rises again on the moors to the south, but does not regain its former height, a gradual diminution taking place all down Airedale. Thus the evidence seems to show that whilst the ice on the Lancashire side of the Pennine axis reached a level of about 1,400 feet above O.D., it probably did not cross the watershed in the gap between Combe and Crow Hills. The evidence derived from the overflow-channels as to the maximum extension of the ice, to be brought forward in the sequel, is in agreement with this conclusion.

A huge boulder of grit, measuring $29 \times 25 \times 21$ feet, and known as the Hitchingstone, lies near the top of an eminence on the moor, nearly two miles south-west of Sutton, at an elevation of 1,175 feet above O.D. There has been a good deal of discussion as to whether the Hitchingstone is a transported block, or whether it has weathered out from rock *in situ*.* It is obviously not *in situ*, and in its present position it could not have fallen from any cliff or crag. There are two thick beds of grit in the immediate neighbourhood from which it may have been derived. One of these forms Earl Crag, situated a mile to the north; the other the hill on which the block lies. Boulder-clay, sometimes

* See Brit. Assoc. Report for 1874, p. 195. Brit. Assoc. Report for 1879, p. 140. Dakyns. Geol. Mag., Dec. II., vol. iv., 1879, p. 96. Adamson. Naturalist, 1886, p. 333.

more than seven feet thick, containing rounded pebbles of Millstone Grit, shale, gannister, and chert, extends above the 1,250 foot contour-line on the hill-slope to the south-west. The block therefore lies well within the glaciated area. Supposing the block to have weathered out before the Glacial Period, it is inconceivable that the glacier should have passed over it and left it in its original position. On the other hand, that a bed of grit over 21 feet thick has, with the exception of the Hitchingstone and some smaller boulders lying near it, been completely removed from the surface in post-glacial times, is contrary to all the existing evidence of the amount of weathering since the Glacial Period. The derivation of the Hitchingstone as a boulder from either of the beds mentioned above does not involve a transport of more than a mile, nor an uplift of more than 50 feet.

Boulder-clay with limestone is found at the head of Lumb Clough, above Sutton. Half a mile north-west of Braithwaite on the northern slopes of *Newsholme Dean*, yellowish sandy boulder-clay runs in low ridges from N.W. to S.E. down the hill side. The bottom of the valley contains much boulder-clay, which also extends up the tributary valley of Newsholme Beck. A section near the Baptist Chapel (Slack Lane) exposed blue boulder-clay containing striated boulders of Carboniferous Limestone and Millstone Grit, together with pieces of shale. Below the junction of Newsholme and Newsholme Dean Becks the boulder-clay is overlaid by coarse gravel and current-bedded sand. There is little drift in the upper part of Newsholme Dean Beck, except near its head, where clayey gravel is exposed in some stream sections. It contains some pebbles of limestone and chert. Gravel two feet thick is exposed on the roadside about 100 yards S.E. of Morkin Bridge. A thin covering of boulder-clay spreads over the flatter part of Keighley Moor to the west of Broad Head. Sandy boulder-clay with chert, grit, gannister, and fragments of shale extends up to the 1,200 feet contour line near Clough Hey Reservoir. The ridge to the south, overlooking the Worth Valley, is bare of drift.

In the *Worth Valley* the boulder-clay forms a thick deposit along the floor and the northern slopes. A boring put down

for the Keighley Fleece Mills Co. revealed 38 feet of sand and gravel (probably some river gravel) resting on boulder-clay which was 32 feet thick. The rock floor is thus at a depth of 70 feet beneath the surface at this point.* Thick bluish boulder-clay weathering to a yellow colour at the surface is exposed at the junction of the Great Northern and Midland lines near Ingrow, and it is also seen in the cuttings of the former line as far as the tunnel east of Haworth. It was also exposed in the cuttings between Haworth and Oakworth Stations on the Midland line. Most of the boulders are of Millstone Grit, the proportion of boulders of limestone being less than that usually found in the drift to the north-west. Above Oakworth the boulder-clay becomes thin, and it is generally weathered completely through. In the large sandstone quarry on Denby Hill, sandy yellow boulder-clay four feet thick contains boulders of grit, limestone, and chert. At Hare Hill, one mile to the west along the Colne Road, a rather flat-topped mound of gravel lies on the side of the hill at an elevation of 1,125 feet above O.D. The section in the pit shows three to seven feet of rudely stratified gravel resting on eight feet of current-bedded sand, with loamy and gravelly layers. The pebbles in the gravel are chiefly of grit, but there are a few of gannister and "bluestone." The latter is a local rock cropping out a little higher up the hill. A small pit on the south side of the Ponden Reservoir exposes a few feet of sand and fine gravel dipping northwards down the slope of the hill. In addition to pebbles of grit, there were noted pebbles of limestone, chert, and Silurian grit.

Yellowish boulder-clay with limestone occurs in Ponden Clough at an altitude of 950 feet. At Two Laws Bridge, half a mile east of the county boundary, a little gravel with chert is seen by the roadside at an elevation of 975 feet. There is very little drift on Haworth Moor, a few rounded pebbles in the soil being all that is seen. Just off the southern edge of the moor near Higher Marsh some boulder-clay with rounded stones was exposed in a roadside section. Boulder-clay may be traced up Bridgehouse Beck to Oxenhope, becoming more

* W. Whitaker, B.A., F.R.S., "Some Yorkshire Well Sections." Proc. Yorks. Geol. and Polyt. Soc., vol. xiii., p. 196.

sandy, and containing less limestone, as the valley is ascended. Above Oxenhope patches of drift occur below a limit on the hill side. In Sun Hill Clough thin boulder-clay, with chert and limestone, were found up to 1,100 feet. In Holden Clough boulder-clay occurs up to 1,050 feet. To the south of Leeming, in Isle Lane, sandy boulder-clay, with encrinital limestone pebbles, was found between the 1,000 and 1,050-foot contours. In Harden Clough and the next one to the east boulder-clay occurred at the same height. Above this altitude, and right up to the Aire and Calder watershed, we have found no glacial deposits, nor even scattered rounded stones, such as are found on areas free from boulder-clay and gravel at lower levels. The same observation applies to Thornton Moor and the high ground to the east as far as the Queensbury ridge. It holds good also for the moors to the west and north-west, except that the boulder-clay or scattered drift pebbles have been found to extend to 1,400 feet in places. The absence of drift deposits, and, indeed, of all signs of glaciation on these moors has been remarked by previous observers. There are many natural hollows in the area where boulder-clay might accumulate and be preserved. It seems that we have here an unglaciated area which separated the ice-sheet of Lancashire from the Airedale glacier. The absence of till from Calderdale, and the occurrence of a boulder-clay with far-travelled erratics on the Lancashire side of the Pennines, immediately to the west, is in agreement with this conclusion. The driftless area described above is the extension northwards along the Pennine ridge of a large unglaciated district on the eastern slopes of the Pennines, of which Calderdale forms a part. On the south side of Airedale the upper limit of the drift diminishes in altitude in an easterly direction, but not at the same rate as the Aire-Calder watershed. The drift surmounts the latter near Bradford, as will be described later (p. 218).

The ridge between the Harden and Worth Valleys is bare of drift, but the striæ recorded above (p. 209) prove that the ridge has been over-ridden by the ice from the north-west. As in the case of the Worth there is much drift in the lower parts of the *Harden Valley*. Above Cullingworth and Wilsden

it is generally thinner and limited in distribution, whilst above Denholme Station no glacial deposits have been found. Weathered boulder-clay more than three feet thick occurs at Manywell Heights (nearly 900 feet above O.D.), and clay with limestone pebbles near the old Copperas Works above 900 feet. These localities, together with the moraine mounds on Hallas Rough Park (p. 205), are the highest localities at which drift has been noticed in the Harden Valley.

In the *Cottingley Valley* boulder-clay with limestone and Millstone Grit boulders extends right up the floor of the valley, and thin drift or scattered drift-pebbles may be found up to the crest of the ridge at Allerton. The moundy features at Sandy Lane Bottom are partly boulder-clay and partly a coarse boulder-gravel. Half a mile above Cottingley the beck has cut a small gorge in the Coal Measures, and has exposed in section its pre-glacial valley, now filled up with boulder-clay. It appears to be somewhat larger than the present channel and has rather less precipitous sides. Higher up the valley the boulder-clay is generally underlaid by a bed of coarse gravel two to three feet thick.

On the high ground between the Cottingley and Bradford Valleys there is very little drift. An exposure, however, near the Chellow Heights Reservoir, almost on the summit of the ridge (850 feet), showed yellowish boulder-clay with limestone, chert, grit, and gannister (striated). Further, large blocks of Millstone Grit are scattered through the fields, and others have been broken up and used in constructing the walls. As these hills consist wholly of the Lower Coal Measures, the grit blocks must have been either uplifted from the valleys or carried across from the hills to the north-west. The ice must have surmounted this ridge at least as far as Allerton (900 feet). On Thornton Heights (1,025 feet) and Swill Hill (1,320 feet) both boulder-clay and scattered blocks of grit are wanting. These hills lie outside the glaciated area.

A thick deposit of blue till lies along the western side of the *Bradford Valley* between Shipley and Bradford. On the north side of Red Beck at Shipley Fields, cuttings for drains exposed about 20 feet of stiff bluish boulder-clay resting on

sandstone. It was weathered yellow to a depth of three feet from the top. The clay contained striated boulders of white and dark blue Carboniferous Limestone ranging up to 18 inches in length, boulders of Millstone Grit up to five feet in length, blocks of Coal Measure sandstone, and a good deal of broken-up shale. The sandstone boulders were sometimes rounded and striated, sometimes angular and not scratched. Between Canal Road and the railway north of Frizinghall Station several exposures showed yellow clay passing down into blue clay. Limestone pebbles were found in both. Amongst the boulders thrown out of one of these cuttings the Lake District andesite mentioned on page 200 was found.

Near the head of Red Beck where a lane crosses it, there is about 50 feet of boulder-clay with boulders of Millstone Grit four feet long. Near Heaton Royd and Heaton Stray yellow clay was seen passing down into blue clay with stones.

The general distribution of the boulder-clay around Bradford has been described by Tate,* and more recent exposures have been described by Dr. Monckman.† Blue boulder-clay with limestone is found up the Thornton Beck as far as Leventhorpe, where it is overlaid by laminated clay and gravel (see p. 225). It also occurs in stream-sections below Clayton on the south side of the valley, but not above the 700-foot contour. Higher up the valley towards Thornton no till has been found, the only superficial deposit being a yellow rainwash, sometimes with a few angular local stones. It is sandy or clayey according to the nature of the rock on which it lies, or which occurs a little higher up the slope. Quite in the bottom of the valley, however, there are a few blocks of Millstone Grit, an explanation of the occurrence of which will be given later (p. 226). Eastwards from Clayton boulder-clay, with limestone and chert boulders, is found at Great Horton (near Close Top Farm at 700 feet above O.D.), Little Horton, and Bowling. South of Bowling the Aire and Calder divide, which to the west is over 800 feet above O.D.,

* T. Tate. "The Glacial Deposits of the Bradford Basin." Proc. Yorks. Geol. and Polyt. Soc., vol. vi., p. 101.

† J. Monckman, D.Sc. Brit. Assoc. Report (Bradford), 1900, p. 754, and Proc. Yorks. Geol. and Polyt. Soc., vol. xiv., p. 851, 1901.

drops below 700 feet at Wibsey Bank Foot. Here the boulder-clay has gone over the watershed. A section pointed out to us by Prof. Kendall, in the railway cuttings half a mile north-east of Low Moor Station on the line to Dudley Hill, shows a small pre-glacial valley filled with boulder-clay. The clay contains boulders of grit, shale, and limestone, and it is weathered to a yellow colour at the top. This section is nearly a mile south of the Aire and Calder watershed. A little clay containing rounded pebbles of Millstone Grit and gannister was noticed on the roadside three-quarters of a mile S.S.W. of Dudley Hill Station, about the same distance south of the watershed.

Along the ridge *east of the Bradford basin* boulder-clay is recorded from several localities, and is very generally distributed along its eastern flanks. A very fine section in the brick-pit at Thornbury is as follows :—

Yellow jointed clay with boulders, passes into	up to 10 feet.
Blue clay with lenticles of sand, which extend up into the yellow clay	3 feet.
Coarse iron-stained gravel	0–2 feet.
Stiff blue boulder-clay	more than 45 feet.

Many large boulders of Coal Measure sandstone, which are often finely striated, lie about in the floor of the pit. Limestone boulders are not common. They are generally very small, but one boulder two feet long was noted. Boulders of Millstone Grit, ironstone nodules, and pieces of shale and coal (sometimes striated), are also found.

In the railway cutting on the Shipley branch of the Great Northern line, where it passes beneath the Leeds and Bradford road, yellowish boulder-clay with chert, grit, and sandstone (striated), fills up an old hollow eroded in the Coal Measures.* Rather over half a mile south of Eccleshill Station the railway cuts through boulder-clay and gravel with limestone and chert pebbles, but the cutting is too much overgrown to make out their relations. Yellow boulder-

* T. Tate, *loc. cit.*, p. 105.

clay occurs on the summit of Stone Hall Hill, Eccleshill, at 700 feet above O.D. The boulders in the clay consist chiefly of Coal Measure sandstone, but include Millstone Grit, Carboniferous Limestone, and Silurian grit, all of which were found striated. The clay contained contorted lenticles of sand, whilst the shaly sandstone beneath was disturbed as if by a thrust acting from W.N.W. to E.S.E. (see above, p. 208). The boulder-clay extends down towards Apperley Bridge.

In the Goole Quarries, to the south of Newlay Station, 30 feet of gravel, resting on the Rough Rock and banked against the hill side, runs up to a height of 75 feet above the river. The gravel is distinctly stratified only in places near the top. The pebbles are chiefly of Coal Measure sandstone, gannister, and Millstone Grit, but small limestone and chert pebbles are fairly abundant. One small pebble of cleaved Silurian slate was also found (p. 199). In a note presented to the British Association in 1900 *the Newlay gravel was stated to mark the last definite* trace of the Airedale glacier in the valley. Although patches of boulder-clay were known to occur north and north-east on the higher ground between Airedale and Wharfedale, it was uncertain whether these deposits might not be due entirely to the Wharfedale glacier. The exposure of boulder-clay with striated boulders of gannister and Millstone Grit in the railway cutting east of Armley Station (Midland Railway), and of yellow boulder-clay ten feet thick with boulders of gannister, encrinital chert, and striated Millstone Grit at Rothwell Haigh, show that the Airedale glacier extended at least four miles S.E. of Leeds. The occurrence of boulder-clay with chert on Whin Moor, and in a quarry at Scholes on the north side of Airedale, also supports this conclusion. We are, however, unable to say how much further the Airedale ice extended.

The wide embayment in the hills in which *Silsden* lies, on the north side of the Aire, is covered with boulder-clay. It extends beyond the northern edge of the map, where it is over 40 feet thick in Cowburn Beck. To the south-west it is seen near Brunthwaite and below White Crag Plantation. In Dirk Hill Sike and Gill Grange Clough the boulder-clay, sometimes very gravelly, is 40 feet thick. It is a stiff blue clay, weathering

yellow at the top, and is full of limestone boulders. In some places it is cemented into a hard conglomerate.

Boulder-clay with abundant limestone pebbles is exposed in deep sections in *Morton Beck*, above Sunnydale Mill, and appears to extend up to about 1,100 feet above O.D. on the moor to the north. In the quarry at the Bingley Sanitary Pipe and Tube Works, a mile and a quarter N.N.E. of the town, a pre-glacial hollow filled with boulder-clay is seen in section. The old valley is about 30 feet deep and 90 feet across at the top. The clay filling the valley is yellow at the top but brownish below. It contains numerous boulders of grit and sandstone, a quantity of shale fragments, and some chert. Several blocks of *Syringopora*, from which the limestone matrix has been dissolved, have also been taken from the clay.

In a large grit quarry at Gilstead, east of Bingley, about four feet of yellow boulder-clay with chert pebbles overlie five feet of stratified silt and gravel which rests on the Millstone Grit. The gravel, which is seen on the western side of the quarry, thins out towards the east.

The most important facts in connection with the distribution of the drift in the Hawksworth and Guiseley districts have been mentioned already (p. 207).

East of the Guiseley Valley the drift is generally thin, and occurs only in outlying patches. At the east end of Apperley Bridge Station gravel was seen banked against an irregularly sloping surface of shale. The gravel passed eastwards into fine sand, and was overlaid by boulder-clay containing limestone.

In the Horsforth Valley yellow boulder-clay with rounded pebbles of grit and sandstone occurs near Scotland, and at the south end of the Bramhope Tunnel.

At the junction of the Horsforth and Otley Roads, in Headingley, boulder-clay eight feet deep was exposed in excavating for foundations. The clay contained striated boulders of grit and gannister. Stony clay, in which two pebbles of chert were found, is exposed in Rowley's Quarry, Meanwood. East of Leeds boulder-clay is known to occur on Whin Moor and in a quarry at Scholes, as mentioned above.

CONTOUR MAP OF THE COTTINGLEY VALLEY.

(Scale, 2 inches to 1 mile.)

Proc. Yorks. Geol. and Polytec. Soc., Vol. XV., Plate XVI.

Reference.

∿∿∿∿	Ice-margin near maximum extension.
.....	,, at 1st stage of retreat, Gaisby Hall (1) and The Bogs (6).
ıılıılıılıı	,, at 2nd stage of retreat, Swain Royd (2) and Chellow Dean (7) (1st cutting).
ooooo	,, at 3rd stage of retreat, Salter Royd (3) and Nailer Rough (8).
+++++	,, at period of re-advance, Salter Royd (3) and Chellow Dean (7), cut down.
—·—·—	,, at 4th stage of retreat, Salter Royd, Nor Hill (4), and Noon Nick (9).
— — —	,, at 5th stage of retreat, Coplowe Hall (5) and Hollins Hall.

A., Allerton. C., Cottingley. C.D., Chellow Dean. C.H., Chellow Heights. H.E., Harrop Edge. S., Sandy Lane Bottom S.R., Stony Ridge. T.L., Toller Lane.

Thus the glacial deposits in Airedale are found abundantly in the main valley and the lower parts of the tributary valleys, but they do not generally extend to the heads of the tributary valleys. On the north side of the dale the glacier coalesced with that in Wharfedale, and the summit of Rumbles Moor alone projected above the surface of the ice. On the south side, where the hills attain to greater elevations, there was a larger unglaciated area. The upper limit of the distribution of the drift, though seldom marked by any moraine, has been traced from an altitude of nearly 1,400 feet on Combe Hill to one of 700 feet to the south of Bradford. The distance between these two localities being 12 miles, the average rate of fall of the surface of the glacier was about 60 feet per mile.

VI.—Glacier-Lakes and their Overflow Channels.

The results of the preceding section show that even at the period of maximum glaciation, the highest parts of the district were unoccupied by ice. Water draining off this more elevated land was unable to escape normally, as the main valley and the lower parts of the side valleys were full of ice, but it collected in the unoccupied heads of the side valleys, which were converted by the ice-barrier into basins.

Thus a series of lakes was formed fringing the edge of the glacier.

The surplus water from one of these lakes had to discharge either over, through crevasses in, or along the margin of the ice, or over the lowest part of the surrounding watershed. Under the first two conditions of drainage no permanent traces of such an overflow would be left after the glacier disappeared; under the last two conditions, the water would cut a channel for itself, which might be identified when the lake had been drained by the melting away of the glacier.

The valleys eroded by the escaping waters of the glacier lakes have the following characteristics* :—

* Prof. Kendall in describing a magnificent series of overflow channels in Cleveland has given their characters in great detail, and classified them according to the relation they bear to the ice front. Q.J.G.S., vol. lviii., 1902, p. 471, and Proc. Yorks. Geol. and Polyt. Soc., vol. xv., 1903, p. 1.

i.—Steeply sloping parallel sides, the parallelism being strictly preserved where the valley curves.

ii.—At each curve the concave bank is more precipitous than the convex, as is the case with the banks of a river, thus indicating that these valleys formed the actual channel in which the water ran.

iii.—The valleys' floors are generally broad and flat. In Airedale they all slope to the south or east.

iv.—The valleys are either streamless or possess very insignificant streams. They generally cut completely through the watershed, quite irrespective of geological structure, the great square-cut notches being very striking in appearance when seen from a distance.

Some small streamless valleys occur which begin quite on the watershed. These may have been produced by water escaping from the ice-front at a time when it just reached but could not cross the watershed.

It will be convenient at this point to consider a good example of one of these overflow channels in some detail.

The ridge which runs from Harrop Edge (1,000 feet) to Stony Ridge, near Shipley, and separates the Cottingley valley from the Bradford basin, is trenched across by a deep ravine called Chellow Dean (see Pls. XVI. and XVII.). The floor of the Dean is generally 30 to 40 yards across, and slopes to the south-east towards the Bradford valley. Its walls, which reach a height of 100 feet, are very steep, and are formed of the sandy micaceous shales and sandstones of the Lower Coal Measures. The tiny trickle of water, which runs through the Dean, is maintained by some springs rising on the hill-side beyond the head of the Dean and in the Cottingley Valley, but it is obvious this tiny stream could never have cut out Chellow Dean, whose characters indicate rapid erosion by a large volume of water. The striking peculiarity about the Dean is the way in which it suddenly opens out at its upper end into the Cottingley Valley. Here its floor is hardly 20 feet above the Cottingley Beck, where the latter flows past the entrance to the gorge.

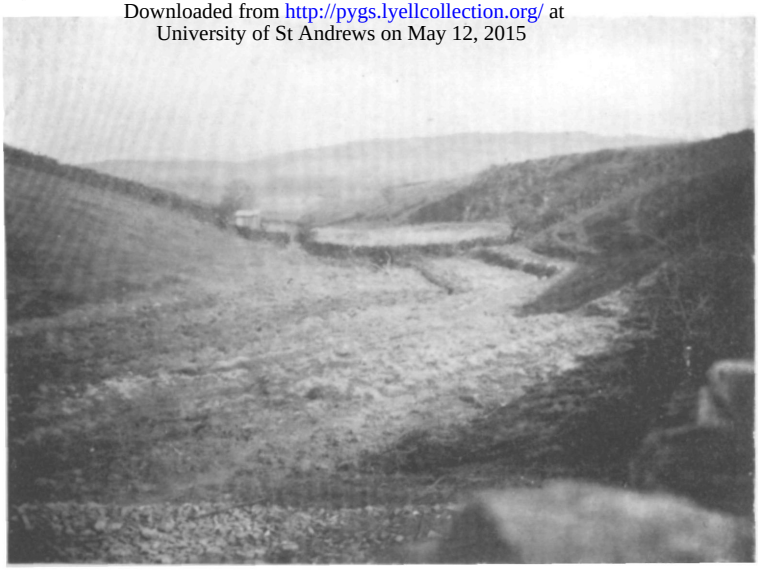

Photo., A. J.

Fig. 1.

DRY VALLEY 1¼ MILES N.N.E. OF BINGLEY, LOOKING EAST.

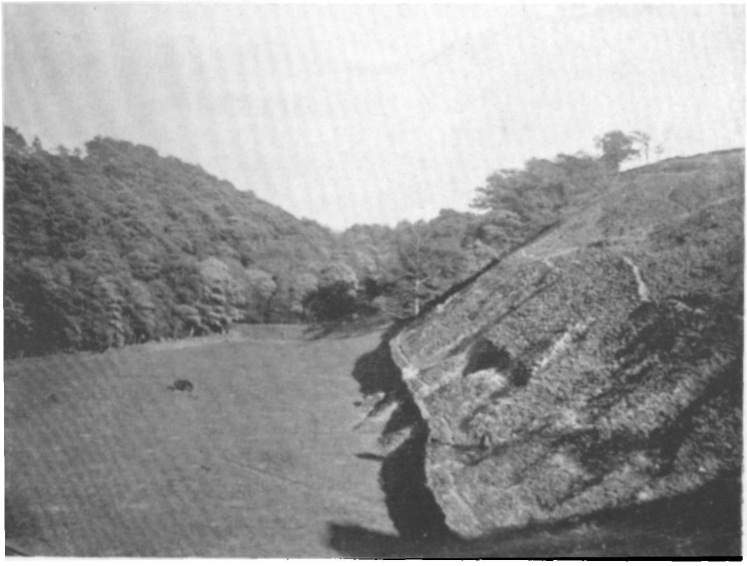

Photo., A. J.

Fig. 2.

CHELLOW DEAN, LOOKING E.S.E. BROAD LEVEL FLOOR ON THE WATERSHED.

A short distance below the lower end of Chellow Dean there is a thick deposit of stratified gravel, composed chiefly of small pebbles of sandy micaceous shale, very like that which forms the sides of the Dean. The pebbles are mostly subangular or rounded, but angular fragments are not uncommon. Small flaky bits of black shale, gannister, and a few rounded pebbles of grit also occur. The lines of bedding in the gravel have a slight dip away from the mouth of Chellow Dean. A small exposure of this gravel is seen about 400 yards below the point where Duckworth Lane crosses the valley. In the next hollow to the west yellowish sand only is to be seen. The deposit has a gently-inclined surface and appears to end off southwards rather abruptly in a steep bank at an altitude of 550-525 feet above O.D. Its altitude corresponds with that of a dry gap which gashes the eastern side of the Bradford basin at Laisterdyke.

It is believed that Chellow Dean was cut out by a large stream discharging from a lake held up in the Cottingley Valley by the Airedale glacier, and that this stream deposited the gravel delta at its lower end, on entering a lake held up by the same glacier in the Bradford basin; at the same time the latter lake had its outlet at Laisterdyke.

It must be observed that Chellow Dean lies for part of its length along a line of fault, as indicated on the Geological Survey Map, but the theory that it is merely a hollow produced by ordinary sub-aerial weathering along the fault is not tenable, because it does not account for that portion of the ravine which is not coincident with the fault. As, however, Chellow Dean and the fault are coincident where they cross the summit of the ridge, it is very probable that a slight original depression in the watershed on the line of the fault determined the place where the Cottingley Lake was first able to find an outlet.

THE GLACIER LAKES AT THE PERIOD OF MAXIMUM GLACIATION.

The lakes which fringed the glacier at the time of its greatest extension will be described first.

The Bradford Lake held up by the ice-front which extended across the valley from Allerton by Leventhorpe and Clayton to

Wibsey Bank Foot discharged by the gap which cuts through the watershed at the last-named place. Traced from the westward the watershed on the south side of the Bradford basin nowhere falls below 800 feet until Wibsey is reached. At Wibsey Bank Foot the summit of the ridge separating the Bradford basin (Airedale) from the Spen Valley (Calderdale) drops sharply to 670 feet, and continues at about that altitude, or a slightly lower one for some distance eastwards. Just at the foot of the steep slope, the watershed is cut through from north-west to south-east by a streamless valley which is about 25 feet deep on the watershed. Followed to the south-east the valley is found to deepen and broaden. Traced to the north-west it shallows after passing through the natural watershed. Its north-eastern side almost disappears, but a shallow depression or a terrace at the foot of a steep scarp is continued for a mile to Close Top Farm, above Great Horton, where it reaches an altitude of 700 feet above O.D. Thus, at the furthest extension of the ice which we have been able to trace, the surface-level of the Bradford Lake must have been at a height of 700 feet above O.D. The surplus water running from near Close Top Farm to the watershed formed, or at least greatly intensified the scarp feature described above, and commenced to cut the gap through the watershed at Wibsey Bank Foot. When the ice-front moved back a little, the overflow took place directly into the gap at Wibsey Bank Foot, and the level of the lake sank to 660 feet.

The cols on the watershed west of Wibsey Bank Foot are not gashed through by valleys. They present the ordinary features of cols and may be described as saddle-shaped. The evidence also from the glacial deposits does not suggest that the ice ever reached up high enough to turn the overflow of the Bradford Lake over them. The same remarks apply to the broad pass, just over 1,000 feet above O.D., which leads from Thornton into the Harden Valley, but the col to the north of Thornton Heights is different. The watershed is at Stream Head Farm, whence a tiny stream flows towards the Bradford basin in a flat and fairly open valley for a third of a mile. The valley then closes in and the stream enters Bell Dean, a narrow gorge over 100 feet deep and a quarter of a mile long. The

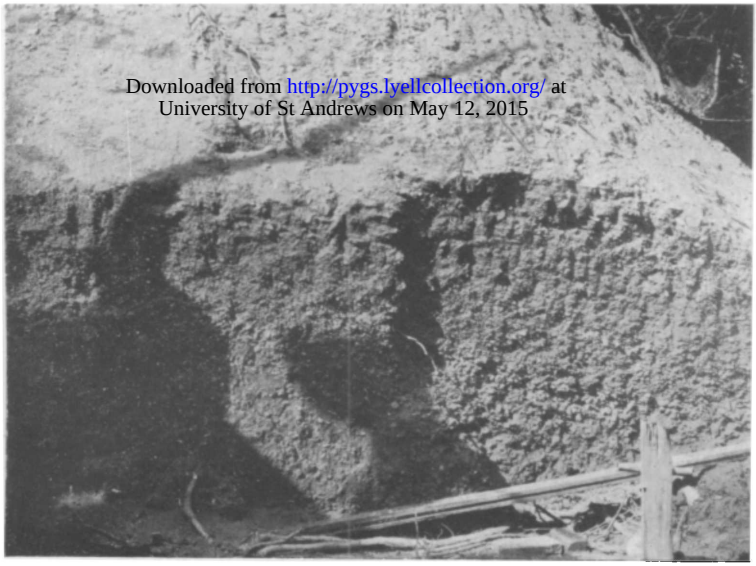

Photo., A. J.

Fig. 1.

SECTION IN GRAVEL DELTA AT LEVENTHORPE. THE CURRENT BEDDING IS SEEN DIPPING TO THE EAST.

↓ CHELLOW DEAN.

Photo., A. J.

Fig. 2.

LOWER PORTION OF SALTER ROYD CHANNEL. (←—) SCARPED HILLSIDE AND SHALLOW VALLEY IN FRONT, ENDING AT LEVEL OF CHELLOW DEAN INTAKE. WOODED SLOPES OF CHELLOW DEAN IN THE DISTANCE.

Dean opens rather suddenly at its lower end into the head of the broad and open valley of Pitty Beck. The altitude of the col at Stream Head is 870 feet, that of the lip of the gorge at Bell Dean 900 feet. It is obvious from the conformation of the ground that the ridge through which Bell Dean is cut was at at one time the watershed between the Bradford and Harden Valleys.

It has already been shown that at the time of the greatest extension of the Airedale glacier, its margin abutted against Harrop Edge immediately to the north of Stream Head Farm. The waters thus impounded at the head of the Harden basin discharged into the Bradford basin and gradually cut down Bell Dean. The level of this lake therefore was at first 900 feet, but by the cutting back of the watershed to Stream Head it was gradually reduced to 870 feet.

Where the waters discharging through Bell Dean would enter the Bradford Lake, viz., near the junction of Pitty Beck with the main stream flowing from Thornton, there is a delta of stratified gravel and silt. It is roughly triangular in shape, and the apex points up the valley of Pitty Beck. A section near Leventhorpe Mill is—

Current-bedded gravel and sand..	about 20 feet.
Micaceous laminated clay	5 feet.
Blue boulder-clay..	25 feet. +

The gravel consists chiefly of water-worn pebbles of sandstone and flakes of shale, similar in character to the rocks in which Bell Dean is eroded. There were also noted a few pebbles of Millstone Grit, chert, decomposing Carboniferous Limestone, and water-worn pieces of coal. The sand is largely made up of particles of shale, so that it is of no use for a building sand. The current-bedding is very marked. It dips at an angle of about 30° away from Bell Dean (see Pl. XVIII., Fig. 1). The gravel forms a gently-inclined surface at two levels, viz., 625–600 feet and 575–530 feet. Near Leventhorpe Hall there is a distinct drop from one to the other. Neither of these levels corresponds with the level of the Bradford Lake at its greatest height. That much of the delta has not been deposited in its present position during the maximum extension of the ice is evident

from the fact that its lower portions rest on boulder-clay. The delta at the maximum extension of the ice being formed in the narrower part of the valley, was washed down and deposited at a lower level when the surface of the Bradford Lake sank (see p. 229).

A deposit probably laid down as the delta of a stream entering the Bradford Lake when at its highest level, was exposed in the valley of a small tributary stream in Clayton. The level of the ground was a little above 700 above O.D. The section exposed is :—

Soil	1 ft.
Yellow (weathered) sandy clay, with sandstone blocks near its base (? rainwash)..	2 ft.
Stratified gravel, consisting of pebbles of sandstone, flakes of shale, and a few pebbles of grit	6 ft.
Yellow loamy sand	2 ft.

The grit boulders which occur in the bottom of the Thornton Valley, above Leventhorpe, were probably dropped from icebergs broken off from the ice-front which held up the Bradford Lake.

When the ice-margin stood against Harrop Edge it must also have reached up to the spur between Harrop Edge and Denholme, as represented on the map. The altitude of the spur is 930 feet—higher than the top of the gorge at Bell Dean. Hence the Harden Lake was separated from a lakelet at Stream Head. They were connected by a stream flowing along the ice-front in the shallow channel which cuts across the spur near Wood Manywells. As the difference in level between the two lakes was only about 25 feet, this channel is not deeply cut. When the ice-front retreated off the spur, the level of the Harden Lake would sink to the level to which Bell Dean had cut, and then to the level of Stream Head col.

A long narrow lake, held up against the hills above Oxenhope, discharged into the Harden Lake by a sharply-cut valley situated between Whinny and Sentry Hills to the south-east of Oxenhope. This channel is streamless, and the road running along its floor is known as Trough Lane (Fig. 1). The level of the Oxenhope Lake, as determined by the original height of

the col at Trough Lane, was about 1,050 feet above O.D., from which level it gradually sank to 1,020 feet before the channel was deserted. The col to the south of Sentry Hill is at a height of 1,180 feet above O.D. It is not cut through by a channel, but is a good example of an ordinary saddle-shaped col. It is evident that the Oxenhope Lake never discharged over this col, and the glacial deposits do not suggest that the Trough Lane channel was ever blocked by the ice. The driftless character of the moorlands to the south has already been remarked upon (see p. 215).

The next lake higher up the dale was one held up at the head of the Worth Valley between two ice-dams. The overflow of this lake into the Oxenhope Lake cut a deep gap across

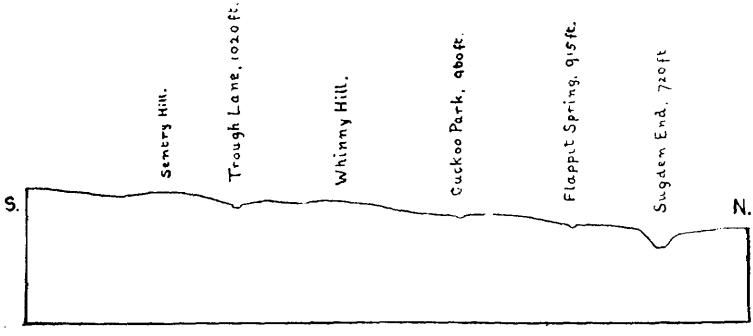

Fig. 1.

SECTION ALONG PART OF THE SUMMIT OF THE RIDGE WEST OF THE HARDEN VALLEY.

the spur of Haworth Moor at Harbour Hole, 2½ miles S.W. of Haworth. This notch has been cut down from about 1,260 feet to 1,230 feet. A slight retreat of the ice-front allowed the water to escape at a considerably lower level, and the Worth Lake sank to 1,115 feet above O.D.

The immediate result of the lowering of the level of Lake Worth was to lay bare the col (1,175 feet) between Combe and Crow Hills, and henceforth the Worth Lake was held up by one ice-dam only. The ice on the Lancashire side, standing close up to the watershed, forced water from the melting ice and the neighbouring slopes to flow over on to the Yorkshire

side of the col. Two dry channels cut through the col at about the same level. The southern one is a deep and well-marked notch, with a broad floor sloping to the east, and covered with peat (see Pl. XIX., Fig. 1). Its intake level is slightly higher (1,130 feet) than the parallel channel to the north (1,120 feet). These two valleys belong to Prof. Kendall's type of "direct overflows." Of these he remarks, "They generally occur singly, one overflow serving for the drainage of a considerable area, but when the watershed is uniform in height, and the ice has at one stage actually surmounted it, then several parallel gutters may be trenched on the outer slope by the water flowing from the ice itself."* No surprise need therefore be felt on account of there being two channels at nearly the same height. They continued to operate whilst the Worth Lake sank to a still lower level. This will be referred to again (p. 238).

The highest overflow channel in the district is situated on the south-west shoulder of Combe Hill, and is known as the Great Nick. This dry gap carried off the water from a lake on the north side of Combe Hill and from the ice itself. Its intake level is 1,325 feet above O.D., and it is nearly 25 feet deep on the watershed. The valley terminates suddenly on the hill side at its lower end, and a gently sloping fan of detritus is traceable under the heather at its foot. The level is about 1,250 feet—that of the Worth Lake at the time when its discharge poured through the gap at Harbour Hole.

Thus at the period of maximum glaciation there stretched along the southern border of the Airedale glacier a series of six lakes, the surface levels of which fell from about 1,325 feet in the north-west to about 700 feet in the Bradford basin. The overflowing waters from these lakes discharged into the head of the Spen Valley, and so into Calderdale. The Spen Valley, as compared with the other valleys opening on the left bank of the Calder is marked by a relatively broad and continuous strip of alluvium, which stretches from its mouth almost up to its head. This suggests that the volume of the stream was formerly greater, and that as its volume diminished the stream aggraded its bed.

* Proc. Yorks. Geol. and Polyt. Soc., vol. xv., p. 9, 1903.

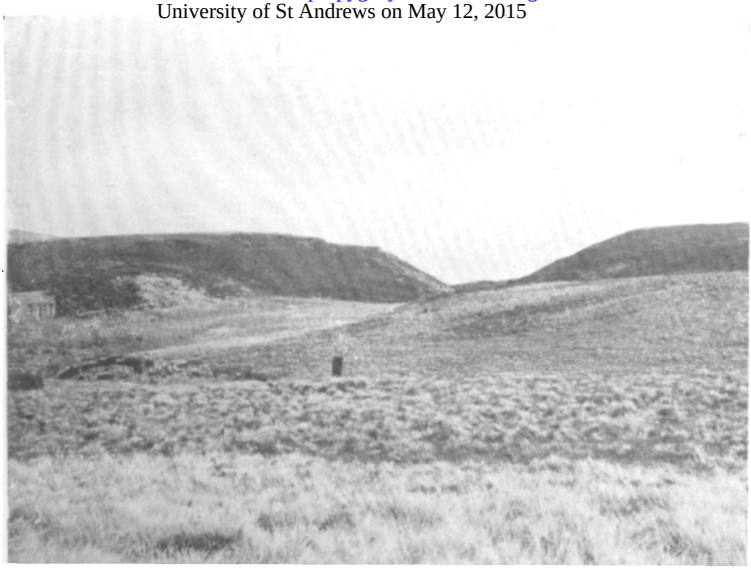

Photo., A. J.

Fig. 1.

DRY VALLEY CUTTING THROUGH THE PENNINE DIVIDE BETWEEN COMBE HILL AND CROW HILL, LOOKING EAST.

Photo., A. J.

Fig. 2.

DRY VALLEY W.N.W. OF STANBURY, LOOKING WEST.

PHENOMENA OF RETREAT.—THE SOUTH SIDE OF AIREDALE.

The effects of the shrinkage of the Airedale glacier was to open lower and lower cols on each watershed, and thereby to lower the levels of the glacier lakes. In this way there was formed a number of overflow-channels on each of the spurs below the levels of the gaps described above. The shrinkage of the ice was not merely intermittent, but oscillatory. On most of the spurs there seems to be evidence of three stationary periods during the retreat, but the slight re-advances of the ice-front, by which deserted channels were again brought into operation and cut down lower than before, renders the correlation of the dry valleys a matter of great complexity. It will be less confusing to describe the valleys taking them spur by spur, than to attempt to arrange in sequence the numerous lake-levels and outlets during the temporary stationary phases of retreat.

The Outlets of the Bradford Lake.—The first stage in the shrinkage of the ice which allowed the Bradford Lake to discharge directly at Wibsey Bank Foot has already been described (p. 224). A further retreat allowed the cutting of the shallow winding channel which runs from Rooley past Bierley Hall into the Spen Valley. The level of the Bradford Lake was at this period about 635 feet, and probably the upper part of the Leventhorpe delta was now deposited.

The only other overflow-channel leading out of the Bradford basin is at Laisterdyke, a gap through which the Great Northern line leaves Bradford. Its intake-level appears to be about 560 feet. Whilst the Bradford lake remained at this level the scarping of the Leventhorpe delta was carried out and the Chellow Dean delta deposited (see p. 226). This channel would remain in operation till the ice had shrunk to a valley-glacier occupying only the main valley of the Aire.

When the Laisterdyke gap came into operation the overflow of the system of glacier-lakes on the south side of Airedale ceased to pass down the Spen Valley. The Laisterdyke gap leads into the valley of Farnley Beck, a tributary of the Aire, which it joins at Leeds. It is very probable that at one period

a lake was impounded in the valley of Farnley Beck and its tributaries by the Airedale glacier, which stretched as a dam across the mouth of the valley from Armley to Middleton. The discharge of this lake would take place by the broad but steep-sided gap* which cuts through the watershed one mile west-north-west of Ardsley Station. The surface-level of the lake would be about 380 feet above O.D.

The Overflow-channels of the Harden and Cottingley Valleys.—The ridges bounding the Cottingley Valley are gashed through by a series of dry valleys, which afford some evidence of the oscillation of the ice-front (see Pl. XVI.). On the east side there is first a marginal channel and shallow valley at the Bogs on the hillside south of Chellow Dean. It commences as a terrace, easily distinguishable from a feature due to a hard bed of rock, at a point 300 yards south of Prune Park, at an altitude just below 850 feet, and runs in a winding course along the hillside eastwards to Chellow Dean. In the lower part of its length, from the Bogs to Chellow Dean, it becomes a shallow valley running obliquely across the contours and ending off in a steep fall on the edge of Chellow Dean.

The second gap on the east side of the Cottingley Valley is Chellow Dean, which has already been described (p. 222). Its intake-level is 720 feet. The third channel is a dry valley commencing at Nailer Rough, two-thirds of a mile north-east of the head of Chellow Dean. It runs in an easterly direction across a gently-sloping plateau and falls into the head of Red Beck, a tributary to the Bradford Beck. It should be noted that its intake-level is 750 feet, i.e., higher than that of Chellow Dean. The fourth channel commences at Noon Nick, a little N. of the last, and at a level of 695 feet. Its course is very remarkable for the valley runs for fully a mile along the edge of the steep escarpment of Stony Ridge, and is in some places not 50 yards from the edge of it. An interesting feature occurs 200 yards west of the point where the high road (Toller Lane) crosses the valley. A sudden descent takes place in the floor of the valley, and at the same time it widens considerably.

*A double fault is marked on the Geological Survey Map as passing through this valley.

Photographed by Godfrey Bingley, Headingley.

DRY VALLEY AT SWAIN ROYD, LOOKING E.S.E. TOWARDS ALLERTON.

Proc. Yorks. Geol. and Polytec. Soc., Vol. XV., Plate XX.

This is caused by the valley cutting down into a bed of shale, whilst previously it was in sandstone. The sudden descent marks the position of an old waterfall.

Two dry valleys run along the outer face of the Stony Ridge escarpment from Shipley Moor Head. Recent excavations show that they are cut in part in shale. The higher one seems to have a double intake, the levels of which are 480 feet and 440 feet. The intake of the lower one is at 430 feet.

The ridge bounding the Cottingley Valley on the west is notched by four overflow-channels, which taken in descending order are as follows:—(1) Gaisby Hall, about 875 feet; (2) Swain Royd, 855 feet; (3) Salter Royd, 840 feet; and (4) Coplowe Hall, 660 feet.

The first three channels are streamless and comparatively shallow winding valleys, whose floors slope steeply in the direction of the Cottingley Valley (see Pl. XX.). The Coplowe Hall channel is a wide, deep channel with a broad floor.

The succession of events in the Cottingley Valley during the shrinkage of the ice was probably as follows:—

When the Harden Lake was discharging by Bell Dean into the Bradford basin, and before it had cut down to its lowest point, a slight retreat of the ice-front opened the Gaisby Hall channel. This gap just cuts through the 875-foot contour, and terminates at its lower end just below the 850-foot contour. It is obvious from the conformation of the ground that when the glacier was standing up to 875 feet on the ridge between the Cottingley and Harden Valleys it would stand at nearly the same height against the hillside at the head of the valley, owing to its opening broadly almost in the direction whence the glacier was coming (see Pl. XXI.). Instead therefore of forming a lake in the Cottingley Valley, the stream from the Gaisby Hall gap flowed between the glacier and the hillside, forming the terrace and shallow valley near Prune Park, and then ran over the watershed, where Chellow Dean was cut out at a later period, and so into the Bradford Lake.

A slight advance then closed the Gaisby Hall channel, and the Harden Lake discharged again for a short period by Bell Dean. On retreat again taking place the Swain Royd channel

was opened and the Harden Lake at a level of 855 feet discharged into the Cottingley Lake. The overflow of the latter escaped over the col at Chellow Dean at about 800 feet and began to cut out that gorge. Before, however, it had cut down to below 780 feet, the ice again retreated. This lowered the Harden Lake to 840 feet by opening the Salter Royd channel, and allowed an escape to the north of Chellow Heights for the overflow of the Cottingley Lake. Thus the Nailer Rough channel was cut, and the level of the Cottingley Lake sank to 770 feet. An advance of the ice-front, which now took place, closed the Nailer Rough channel and turned the overflow of the Cottingley Lake through Chellow Dean again. This time it was cut down from 780 feet to 720 feet. The above advance required to close the Nailer Rough channel need only be a very slight one, on account of the position of the head of the channel facing up the valley of the Aire whence the ice was coming (see Pl. XXI.). The ice simply pushed up the Cottingley Valley, but did not close the Salter Royd channel, which was operating as the outlet of the Harden Lake. However, it pressed in against the lower end of this channel and caused the stream to flow towards the head of the Cottingley Valley close in against the hillside. The stream cut into the hillside and produced the strongly-marked scarp and shallow valley which runs from the Salter Royd gap obliquely across the contours towards Chellow Dean (see Pl. XVIII., Fig. 2). This scarp and valley end in a flat at 720 feet—the level of the intake of Chellow Dean.

Had the ice in this oscillation advanced sufficiently far to close the Salter Royd channel as well as the Nailer Rough one, the Swain Royd channel would have been brought into operation again and would have been cut down to 720 feet. But it is not so cut down ; it distinctly terminates on the slope of the hill at 780 feet. This is the level to which Chellow Dean was cut down just before the ice retreated to open the Nailer Rough channel.

After this advance, during which Chellow Dean was cut down to 720 feet, the ice retreated further than it had done before. The Nailer Rough channel was now too high to operate as the outlet of the Cottingley Lake. The channel commencing at Noon Nick (695 feet) was cut, whilst the ice-margin must

have stood along the edge of the Stony Ridge escarpment. The overflow of the Harden Lake at this period took place by the Salter Royd channel, and perhaps later between the ice-front and the scarp near Nor Farm at 770 feet.

At a still later period the Harden Lake discharged through the gap near Coplowe Hall (660 feet), whilst the Noon Nick channel was deserted and the ice-margin stood along the lower slopes of the Stony Ridge escarpment, the overflowing waters escaping by the channels at Shipley Moor Head. At this stage the glacier probably terminated at the Tong Park moraine. If there was any lake in the Bradford basin it must have discharged through crevasses in the ice, which would doubtless become effective when the glacier became thinner and shorter.

The Outlets of the Oxenhope Lake.—The shrinkage of the ice from the ridge east of the Worth basin opened an outlet at Cuckoo Park, situated about a mile north of the Trough Lane channel (Fig. 1). This is a streamless valley with an intake-level of about 960 feet. On the watershed, where it coincides with a line of fault, it is shallow. The valley, however, deepens rapidly towards the east, and runs in a winding course through a thick bed of Millstone Grit. It terminates at the 775-foot contour, just below the bridge on the main road from Keighley to Halifax. In the lower part of its course it holds a small stream, which rises in springs 300–400 yards south of the valley. At its mouth a deposit of gravel and sand, with an irregular sloping surface, spreads down the slope of the hill towards Cullingworth. On the sides of Manywells Beck the gravel is in places more than nine feet thick. The stones seem to consist entirely of sandstone and grit, generally somewhat decomposed; they are water-worn, but not as a rule well-rounded.

The next overflow on the retreat of the ice took place by the streamless valley near Flappit Spring, situated about half a mile to the north of the last. This channel runs as a deep, steep-sided valley, right up to the watershed, where it ends suddenly in a steep wall of grit. There is barely any notch through the watershed (915 feet). The valley was doubtless eroded chiefly by the cutting back of a waterfall, and we may suppose it to have been deserted before the divide was completely

cut through. Gravel, exposed for ten feet in an old pit, overlies the grit on the south side of the dry valley at an elevation of 840 feet. Towards its lower end the channel narrows and then opens out into a normal valley at 725 feet. Here are several small moundy features in which an obscure section showed about three feet of yellow loamy sand and stones.

On further shrinkage of the ice the great gap was opened at Sugden End, directly east of Haworth. The original height of this col was probably about 800 feet. At present it is 720 feet. The Sugden End overflow-channel consists of three chief portions. The first, in which a small reservoir lies, is a broad flat-floored channel with a very steep and fresh scarp on the south side about 150 feet high. On the north side it is contained by a low bank of rubbly grit with boulder-clay banked against its outer face. This portion of the channel leads into the short but deep gap which cuts through the watershed. It is a conspicuous opening through the hills to be seen for miles to the east or west of it. As already mentioned it has been cut down from about the 800-foot contour, the original dip in the watershed being largely due to the fault which crosses it here. The channel continues in an easterly direction, but near Sugden House it turns slightly to the south, forming a valley with a broad floor and very steep sides excavated in the flank of the hill on the south side of Eller Carr Beck. At its lower end it turns to the north-east and terminates at the 650-foot contour. The Harden Lake, into which the stream poured, was at this period discharging by the gap at Coplowe Hall (p. 231). The characters of the Sugden End channel, which strongly scarps its southern bank at its intake and forms an " in-and-out " channel near its termination, indicate that the ice stood close up to it, at least during its initiation.

Stages in the discharge of the Worth Lake* intermediate between the Flappit Spring and Sugden End overflow-channels are indicated by the scarp and shallow channel on Brow Moor, to the east of the head of the Flappit Spring Valley, and by the

* It will be shown below that before this period the Oxenhope and Worth Lakes coalesced to form a single lake, which it is convenient to speak of as the Worth Lake.

small feature, near Brow Top, just south of the intake of the Sugden End gap. The levels of the Worth Lake at these very temporary periods would be about 905 and 850 feet respectively. A small lateral intake also enters the Sugden End channel on its north side at 730 feet.

The ridge between the Worth and Harden Valleys to the north of the Sugden End gap remains considerably higher than that gap, until it drops suddenly towards the main valley near Keighley. As might be expected the ridge is not cut through by any overflow channels. The Sugden End gap would carry off the waters of the Worth Lake, whilst the ice was retreating down to the main valley. It was thus probably in operation for a comparatively long period. Remains of a possible beach belonging to this stage are indicated by the terrace, which runs along the hillside from the Sugden End gap southwards towards Oxenhope. Its altitude is 720 feet—that of the intake of the Sugden End Valley.

The terrace and shallow channel on the slope of the ridge facing the main valley of the Aire and east of Long Lee, near Keighley, may perhaps be due to the escape of the Worth Lake overflow between the edge of the glacier and the hillside. Its altitude is about 720 feet above O.D., and it probably marks an oscillation of the ice-front shortly before the Sugden End gap was deserted.

The Outlets of the Worth Lake.—The first stage of the retreat, when the discharge of the Worth Lake took place by the gap (Wether Hill Clough) below Harbour Hole at 1,120 feet, has already been mentioned (p. 227). A sloping terrace of sandy drift, with large angular and rounded blocks of grit and a pebble or two of chert, occurs near the lower end of this channel, where the stream would enter the Oxenhope Lake. The altitude is 960 feet. This corresponds to the altitude of the overflow at Cuckoo Park, whence the Oxenhope Lake discharged during the first stage of the retreat of the ice.

A further shrinkage of the ice lowered the waters of the Worth Lake to the shallow gap, marked " Stanbury Height " on the six-inch map. This gap lies on Haworth Moor one mile south-west of the church. Its intake-level is just under 975 feet.

It is very probable that on account of the conformation of the ground (see Pl. XXI.) the Oxenhope Lake was still discharging at Cuckoo Park. The surface-level of this lake was therefore about 960 feet. The difference in the levels of the lakes was thus barely 15 feet. This explains why the gap at Stanbury Height is such a shallow one, being cut down only a few feet.

By the time that the ice had retreated sufficiently to allow the Flappit Spring overflow to operate, the Haworth ridge was sufficiently free from ice to admit of the waters of the Worth Lake passing round the spur. The Worth and Oxenhope Lakes thus coalesced to form one large lake with arms stretching up Bridgehouse Beck towards Oxenhope, up the Slade Beck to the south of Stanbury, and up the main valley of the Worth.

In addition to the above another complication ensued, but with results of an opposite nature. The retreat of the ice combined with the rapid lowering of the surface-level of the Worth Lake exposed the ridge on the north-west side of the Worth Valley. A lake was then formed at the head of the Newsholme Dean Beck, which discharged into the Worth Lake.

The Outlets of the Newsholme Lake.—The highest overflow of this lake took place by Dry Clough, rather over a mile west of Oakworth. It commences as a very shallow valley on the watershed, at 1,100 feet, but deepens rapidly and runs as a streamless valley down to the 925-foot contour, where it ends. It appears to have been deserted about the time that the Flappit Spring channel was coming into operation.

The retreat of the ice opened a channel at Griff Wood to the north-west of Oakworth. This valley is quite dry and terminates at 840 feet in a level fan of detritus, through which an iron rod passed for nine feet before reaching rock. On following the valley upwards towards the north-north-west, it is found to trench completely through the watershed. Shortly after this, it makes a sharp bend to the west-north-west, and runs as a shallow channel along the hillside for about 300 yards. This feature, viz., the deflection of the overflow-channel at its intake away from the ice has already been noticed in connection with the dry gap at Wibsey Bank Foot (*p.* 224). It also occurs

both at the upper and lower ends of the Salter Royd gap (p. 231), and is more or less clear in the case of other overflow channels. It is due to the ice standing actually up to the head of the dry valley and forcing the water to flow for some distance between the ice and the hillside previous to its escape across the divide. The level of the Newsholme Lake at the time the Griff Wood channel was in operation was just under 900 feet.

A slight shrinkage of the ice opened a channel at Wide Lane immediately to the east of the last. This channel has an intake-level of 860 feet. It is shallow at its head, but deepens considerably in a sudden descent of its floor, where it passes through the highest part of the ridge.

Between the lower ends of the Wide Lane and Griff Wood channels there is a small rounded hill, known as Boston Hill, and isolated by a small valley which slopes steeply from the end of the Griff Wood channel to the Wide Lane Valley. A small section near the top of the hill exposed yellowish clay with rounded and angular stones, but it is not certain that the whole hill is composed of drift. A boring by iron rods put down in the middle of the Wide Lane channel, opposite the end of the cross-valley from the Griff Wood channel, passed through 18½ feet of peat, gravel, blue clay, and gravel without reaching "solid" rock. At the mouth of the cross-valley solid rock was reached at depths varying from two and a half to five feet. The surface was here about three feet above the place where the first boring was put down. The Wide Lane channel would thus appear to have been cut down about three yards below the mouth of the cross-valley. The origin of the latter is very obscure.

A small oscillation of the ice-front, before the Griff Wood channel was finally deserted, is probably indicated by the small cut, which runs from the upper part of the Griff Wood channel towards the Wide Lane one along the northern edge of Griff Wood.

The next overflow-channel is a shallow valley cutting through the watershed at Race Moor Farm (Cure's Lathe on the old edition of the 6-inch map), about 400 yards east of the Wide Lane Valley. Its intake-level is 870 feet above O.D.

This valley ends in a flat cone with a steep outer edge, an excavation in which was reported to have shown fine yellow sand four feet thick. The soil at the top was a yellow loam. This channel was in operation for only a short period, and was probably eroded during an oscillatory movement of the ice, since the Wide Lane channel cuts down to a lower level at its termination.

At Branshaw Wood, behind Oakworth House, an overflow-channel runs as a winding valley 50–75 feet deep completely through the watershed. Its original contours are somewhat obscured by quarrying operations. At its head, where it opens out into the Newsholme Beck Valley at 845 feet, it shows the marked deflection to the west away from the edge of the ice, which has already been noticed in connection with the Griff Wood Valley. This channel must have carried off the waters of the Newsholme Lake, when the Worth Lake was discharging by the gap at Sugden End. It terminates in the Worth Valley in nearly level ground at 720 feet, which is the intake-level of the Sugden End gap.

The Outlets of the Glusburn Lake.—It will be necessary at this point to refer back to the conditions which obtained around the head of the Worth Valley at the period of maximum glaciation. A stream pouring through the "Great Nick" on the south-west shoulder of Combe Hill entered the Worth Lake, which discharged through the Harbour Hole channel at a level of about 1,250 feet. The effect of the shrinkage of the ice in allowing the Worth Lake to discharge at lower levels (1,120 and 960 feet) was to expose the low part of the Pennine divide between Combe and Crow Hills, and the ridge between the Worth and Newsholme Valleys. Over both these ridges lakelets, held up by the ice, discharged into the Worth Lake as already described (pp. 227 and 236). Another effect was to cause the desertion of the Great Nick on Combe Hill, and allow the waters to escape at a lower level round the north-east shoulder of the hill into the Newsholme Lake. The case is almost parallel to the one already described (p. 231), where the Harden Lake discharges at the maximum extension of the ice into the Bradford Lake, and during the retreat of the ice into the Cottingley Lake.

The waters thus discharging into the Newsholme Lake were held up by a long ice-front against the northern slopes of Combe Hill. There was hardly a lake in the Glusburn Valley in the same sense as there was one in the Harden Valley, but it will be convenient to speak of the water impounded against the northern slope of Combe Hill as the Glusburn Lake.

It has already been pointed out that there was a movement of the ice from west to east across the Pennine divide to the north of Combe Hill (p. 200). The ice therefore was pressing in on the western flanks of the hill, and the impounded water naturally found its lowest escape across the north-eastern shoulder. That during the period of maximum glaciation the

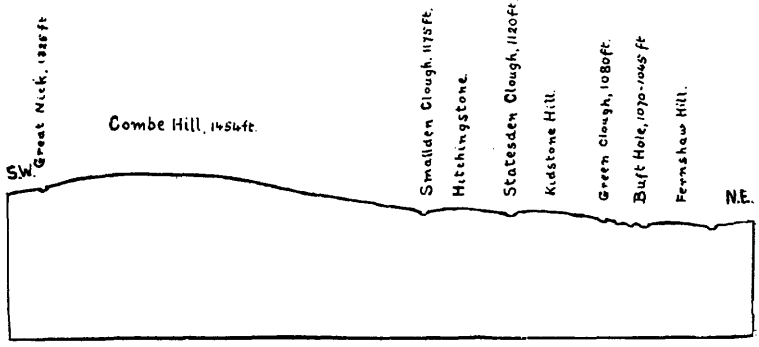

Fig. 2.

SECTION ALONG PART OF THE SUMMIT OF THE RIDGE ON THE S.W. SIDE OF THE GLUSBURN VALLEY.

water escaped across the south-west shoulder of the hill is due to the peculiar conformation of the ground in the vicinity.

The highest overflow channel to be noted is Smallden Clough, a well-marked valley cutting through the watershed one mile to the south of Earl Crag. Its intake-level is 1,175 feet.

The next outlet was Statesden Clough, a deep gorge through the watershed, running parallel to Smallden Clough and about one-third of a mile to the north-east of it. These two valleys isolate the hill on which the Hitchingstone lies (p. 212). Statesden Clough has an intake level of 1,120 feet, and opens out at its lower end at the 1,000-feet contour line.

A shrinkage of the ice opened Green Clough, which is a shallow valley commencing at 1,080 feet and winding round the eastern flanks of Kidstone Hill. Immediately to the east there is a series of four shallow dry gaps, all of which lead into Buft Hole, a dry valley about 50 feet deep, the intake-levels varying from 1,070 to 1,045 feet.

Beyond Fernshaw Hill an overflow channel with a double head enters Buft Hole on its left bank. The altitudes of the intakes are about 1,030 and 1,015 feet respectively.

The overflow-channels enumerated above almost all exhibit at their intakes the deflection to the west, which indicates that the ice-front stood close up to each one at least for some period during its formation. The occurrence of loop channels or "deserted ox-bows"* near their lower ends indicates not only the presence of the ice-front, but also local oscillations of the ice whilst each of the valleys, in connection with which an "ox-bow" occurs, was being eroded.

On Cutshaw Moor, a mile and a half to the east-north-east, the watershed is again cut through by two channels. The higher one commences at 1,050 feet above O.D. and runs as a shallow dry valley obliquely across the contours to Cutshaw Farm, where it passes through the watershed. It is joined near the farm by another shallow dry valley, the intake-level of which is a little below 1,000 feet. These valleys, therefore, cut through the ridge at the same levels as the gaps at Buft Hole described above. This is explained by the presence of the spur, which runs northward towards Sutton from the highest part of the ridge west of Cutshaw. When the impounded waters of the Glusburn Lake were discharging by the Buft Hole channels into the Newsholme Lake, the ice must have stood up against this spur. To the east of the spur the hollow in the angle between it and the main ridge contained a lakelet which discharged quite independently by the Cutshaw channels into the Newsholme Lake.

It is difficult to say at what level the Cutshaw channel ends, but it may go as low as 850 feet. This would indicate

* Prof. Kendall loc. cit.

that it was in operation when the Newsholme Lake discharged by the Branshaw Wood gap.

The north-west shoulder of the ridge below the intake-level of the Cutshaw channel presents many terraces in the solid rocks, but no distinct gaps through the ridge were noticed.

PHENOMENA OF RETREAT.—THE NORTH SIDE OF AIREDALE.

At the period of maximum glaciation the conditions did not admit of the formation of any lakes fringing the north side of the Airedale glacier. During the retreat of the ice, however, lakelets were formed at the heads of Morton and Howden Becks.

The Outlets of the Morton Lake.—The highest outlet of the Morton Lake is indicated by Spa Dyke, a very shallow channel situated one mile east-north-east of Morton. It cuts through the ridge which separates the valley of Morton Beck from that of Eldwick Beck, and carries off the water of some springs which rise within the natural drainage area of Morton Beck. The surface level of the Morton Lake at this period was 940 feet. A lower outlet occurs at Morton Stoop, a well-marked gap, through which the road from Morton to Hawksworth runs. Its intake-level is 905 feet.

The shrinkage of the ice off the spur opened successively a number of small channels, some of which do not quite cut through the watershed. The lowest channel, however, is a large valley with steep sides and a flat floor. It is situated 1¼ miles N.N.E. of Bingley, and slopes in the direction east by south (see Pl. XVII., Fig. 1). After cutting through the watershed it turns at its upper end almost due north, and runs for some distance as a shallow valley nearly parallel to the contours. The deflection is thus away from the ice-front, as in the cases noted on the south side of Airedale, and is due to a similar cause. The surface level of the Morton Lake would at this period sink from 770 to 745 feet above O.D.

There is no evidence in the presence of overflow channels that glacier lakes ever existed in the valleys of Eldwick or Hawksworth Becks. It has been shown that during the retreat of the Airedale ice the Wharfedale ice occupied the north-eastern

lip of the Hawksworth Valley (p. 208). If there was an ice-dammed lake in the Hawksworth Valley at this period, it must have discharged over or through the ice-barrier, since no part of the Hawksworth ridge is cut through by an overflow-channel. Consequently it is impossible to give the surface level to which such a lake might rise, but it may have been sufficiently high to have covered the broad col (705 feet) behind Hope Hill, and to have formed a lake confluent with water impounded in the Eldwick Valley. Into this lake the Morton Lake would discharge.

It might be expected that at a later period the level of the Hawksworth Lake would sink below the level of the col behind Hope Hill, and that the Eldwick Lake would discharge over the col or round the southern flank of Hope Hill. There is, however, no evidence of the passage of such an overflow.

The Outlets of the Howden Lake.—The Howden Lake, held up at the head of Howden Beck, about two miles E.S.E. of Silsden, discharged over the spur which forms Rivock Edge, into the Morton Lake. The overflow channel is a steep-sided winding valley with a broad peaty floor. It exhibits very clearly a feature which has been mentioned as characteristic of the overflow channels, viz., that the bank on the outer curve at each bend is distinctly steeper than the bank opposite on the inside of the bend.

It is perhaps worth while pointing out that whilst the Rivock overflow channel does not coincide with a line of a fault, the spur through which it cuts is crossed by two faults. These trend across the spur parallel to and north-east of the overflow channel, but there are no valleys through the watershed along their courses.

The surface level of the Howden Lake when it discharged through the Rivock overflow channel was a little below 1,100 feet above O.D. At a later period the overflowing waters seem to have escaped by a shallow channel at the foot of Rivock Edge. This channel, which is partly filled with peat, indicates a discharge at about 1,000 feet. No overflow channel was noticed at a lower level.

Before leaving the subject of overflow channels, an anomalous dry valley, exhibiting several of the characteristics of the overflow channels, should be mentioned. This valley is situated on the south side of the River Worth, a mile and a half due west of Haworth, and a few hundred yards west-north-west of Stanbury. It differs from the normal overflow channel in that it does not trench through a watershed, but occurs near the bottom of a large valley not many feet above the modern stream. It is a curved valley cut into the slope of the hill, and it possesses steep sides with a broad floor sloping to the east. The altitude of its floor at the intake is 705 feet above O.D. (see Pl. XIX., Fig. 2). There is not the slightest trace in the main valley of any drift dam by which the River Worth might have been obstructed and forced to cut a new channel for itself, as the River Aire was compelled to do by the Nab Wood moraine (p. 203). The valley has many characters in common with Prof. Kendall's type of "in-and-out" channels, and the only suggestion that we can offer as to its origin is that it was caused by the water flowing round a lobe of ice (or perhaps a mass of ice isolated by irregular melting) which lay upon the north slope of the Worth Valley, and obstructed the water flowing from the higher parts of the valley at this place.

We have no knowledge as to the manner in which a glacier would disappear from a country consisting of a series of rather narrow valleys separated by high ridges, which directly cross the path of the ice. The complex series of overflow channels described above show clearly that the retreat in Airedale was intermittent, and that during its progress slight readvances took place. Within the area which was once ice-covered, there is scarcely sufficient evidence to allow of the marking of the position of the ice-edge throughout the length of the dale during the various phases of retreat. The positions of the overflow channels are determined as much by the shape of the ridge through which they are cut as by the nature of the retreat of the ice. A favourably-situated gap like that of Sugden End (p. 234) persisted, and was deeply excavated during the cutting of several valleys at different heights on the ridges to the east and west of it. The highest dry gaps, however,

are readily correlated with the evidence of the limits of the drift, and a complete series of lakes and overflow channels may be traced corresponding to the period of maximum extension of the ice.

VII.—Conclusions.

The nature and distribution of the glacial deposits and the evidence from striated rock-surfaces indicate a general ice-movement in Airedale from N.W. to S.E. The Airedale glacier is by no means of local origin, but should rather be regarded as a great composite lobe of ice receiving its original supply of ice and stones in part from the ice-sheet which invaded Lancashire from the north and north-west, but chiefly from the snow-fields which had accumulated upon the extensive high plateau of North West Yorkshire.

The Irish Sea ice-sheet pressed in upon the Lancashire plain, reached far up the western flanks of the Pennines, and prevented any flow of ice from the N.W. Yorkshire uplands down the natural slope of the ground towards the Irish Sea. Consequently ice accumulated to a great thickness in the basin-like hollow in which Skipton, Hellifield, Gisburn, and Barnoldswick are situated. Being unable to escape westwards the ice moved across the comparatively low and open country in an easterly direction towards Skipton, and a portion of it continued in this direction, passing through the depression in the hills leading into Wharfedale.

The wide and low-lying valley of the Aire with its natural slope to the south-east afforded an unobstructed outlet for the constantly increasing accumulation of ice. Hence most of the ice flowed out in this direction. The widespread distribution of the glacial deposits clearly indicates that when the ice-sheet was at its greatest extension the moors north and west of Combe Hill were completely over-ridden. Stretching away to the east, north, and west from Combe Hill was one vast sea of ice. from which the highest part of Rumbles Moor stood out as a "nunatak." Southwards, however, a very different scene appeared. Although drift has been traced high up the western slopes of the Pennines, there is no evidence to show that any lobe of ice has crossed the Pennines between Combe Hill and the

head waters of the Calder, and east of this portion of the main watershed occurs an undoubted unglaciated area. No glacial deposits whatever have been observed, nor do the rocks exhibit glaciated or *moutonnée* outlines, whilst masses of grit are seen weathered into the most fantastic shapes. Passing round the northern flanks of Combe Hill the ice edge may be traced almost due south and then E.S.E. across Haworth Moor, and along the moor edge south of Oxenhope, its altitude gradually diminishing. Then, turned north-eastwards by the moors east of Oxenhope, the ice again pushed up the Harden Valley beyond Denholme, and passing round Harrop Edge crossed into the Bradford basin. The lower parts of this basin up to Leventhorpe and Clayton were completely filled with ice, which also over-rode the eastern lip of the basin between Dudley Hill and Idle Hill. The drift-filled valley seen in section, near Low Moor Station, points to the conclusion that at the maximum extension a lobe of ice stood over the broad depression in the watershed between the Aire and Calder at Wibsey Bank Foot. From here the edge of the ice continued in an east-south-easterly direction, probably passing to the north of Drighlington.

On the northern side of Airedale, after passing Rumbles Moor, the Airedale and Wharfedale ice again coalesced. The Airedale glacier passed considerably beyond Leeds as the sporadic patches of boulder-clay and gravel containing erratics from the west on Whin Moor, at Scholes, and at Rothwell Haigh indicate. The distribution of the moraine mounds and the arrangement of the till in the transverse valley east of Rumbles Moor seem to indicate that the Airedale ice began to retreat before the Wharfedale ice in that district.

The position and direction of the striated rock-surfaces on Harden Moor, the packing of the till on the south-eastern slopes of the hills, and the distribution of Carboniferous Limestone and Silurian boulders, prove a general ice-movement from the north-west not only down the main valley of the Aire, but also transversely across the ridges separating the tributary valleys. There is no evidence that the tributary valleys, such as the Worth and Bradford basins, ever held local glaciers which originated on the hills at their heads and flowed down towards

the main valley. The striæ to the south of Shipley were undoubtedly produced by ice moving from the north-north-west, and pushing into the mouth of the Bradford Valley. The striæ near Cullingworth were produced by ice moving from the north-west, and not by a glacier flowing down the Harden Valley from the hills above Denholme.

The average rate of fall of the surface of the Airedale glacier as indicated by the upper limit of the drift was about 60 feet per mile.

The glacier occupying the main valley of the Aire and the lower parts of its tributary valleys obstructed the normal courses of the water flowing from the unglaciated area on the Pennine Hills, and impounded it in the upper parts of the tributary valleys. In this manner a chain of six lakes was formed fringing the south-western margin of the ice. The surplus waters discharging from each lake passed into the next lake to the south and east, whilst the discharge of the lowest (the Bradford Lake) escaped across the main watershed into the Spen Valley, and so into Calderdale. The outlets and surface-levels of each of these lakes are identified by the channels which the discharging streams eroded. These channels exist as an anomalous series of dry valleys, which trench through the hills and are entirely independent of the natural drainage of the country. As the ice melted away the lakes were enabled to discharge at lower levels, and during the temporary halts and short re-advances of the ice, several series of overflow-channels were eroded. The relative lengths and heights of the spurs separating the lakes occasioned sometimes the coalescence of two lakes previously distinct—sometimes the formation of a new lake. This irregularity of the topographical features, combined with the oscillatory retreat of the ice, has rendered the system of overflow-channels eroded during the retreat of the ice very complex and their correlation a matter of great difficulty.

On the northern margin of the Airedale glacier a chain of lakes was in existence for some time during the shrinkage of the ice.

Evidence for one period of glaciation only has been obtained. The yellow clay passing down into the blue boulder-clay can

only be considered as a product of atmospheric weathering, whilst the more sandy nature of the drift at higher levels is due to the larger proportion of local detritus which it contains. The ice flowed down Airedale from the comparatively open country to the north-west of Skipton. Its upper layers, when they impinged against the hills, may therefore be expected to have borne a smaller quantity of stones and mud than the lower layers constantly moving over the surface of the ground.

The easterly termination of the glacier has not been fixed. If, as is possible, it entered Lake Humber,* its termination may well be indefinite. Terminal moraines, however, which accumulated during halts in the general retreat occur in the main valley. They lie in the more constricted portions of the valley.

The hills south and west of Airedale, although reaching to a height of 1,700 feet in Boulsworth, were not over-run by the ice, and were probably free from snow in summer. At any rate the snow was sufficiently melted off them to prevent the formation of local glaciers. It seems that the snow-line in Airedale during the Glacial Period cannot have been below 1,500 feet, and was perhaps more than 1,700 feet above Ordnance Datum.

A large portion of the work, of which this paper is a record, was carried on whilst the authors were closely in touch with Prof. Kendall, whom they desire to thank for his generous help. In particular, Prof. Kendall's work on similar problems in Cleveland has thrown a flood of light upon the interpretation of the dry valleys in Airedale.

We also thank Mr. Godfrey Bingley for the photograph from which Pl. XX. is reproduced.

* P. F. Kendall. Q.J.G.S., vol. lviii., 1902, p. 567.

ILKLEY
WATERSHED
RUMBLES MOOR
RIVOCK
KILDWICK
SILSDEN
HOWDEN BECK
CLUSBURN BECK
SUTTON
AIREDALE
WHARFEDALE
OTLEY CHEVIN
WATERSHED
KNORNSHAW
HITCHINGSTONE
CUTSHAW
NEWSHOLME DEAN
KEIGHLEY
MORTON
REVA
HAWKSWORTH
GUISELEY
YEADON
LONGLEE
EDWICK BECK
HOPE HILL
BAILDON
TONG PARK
COMBE HILL
GRIFE WOOD
OAKWORTH
BINGLEY
HORSFORTH
WORTH
LAKE
PONDEN
STANBURY
WORTH VALLEY
HAWORTH
SUGDEN END
FLAPPIT SPRING
CULLINGWORTH
HARDEN BECK
NAB WOOD
SHIPLEY
APPERLEY BRIDGE
NEWLAY
COTTINGLEY
STONY RIDGE
ECCLESHILL
CROW HILL
HARBOUR ROLE
CUCKOO PARK
WHINNY HILL
OXENHOPE LAKE
TROUGH LANE
STREAM HEAD
HARROP EDGE
DENHOLME
HARDEN LAKE
SENTRY HILL
ALLERTON
CHELLOW DEAN
BELL DEAN
THORNTON
BRADFORD
BRADFORD LAKE
CLAYTON
HORTON
LAISTERDYKE
PUDSEY
FARNLEY BECK
OXENHOPE MOOR
WATERSHED
QUEENSBURY
WATERSHED
ROOLEY
WIBSEY BANK FOOT
SPEN VALLEY

Proc. Yorks. Geol. and Polytec. Soc., Vol. XV., Plate XXI.

CONTOURED MAP OF PART OF AIREDALE.

SCALE: 1⅛ inch to 1 mile.

Overflow Channels.

Edge of the Ice near its Maximum Extension.

Striated Rock-surfaces.