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PROCEEDINGS

OF THE

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1903—1905.

WITH SIXTY-THREE PLATES.

EDITED BY

WILLIAM LOWER CARTER, M.A., F.G.S.,

AND

WILLIAM CASH, F.G.S.

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PROCEEDINGS

OF THE

YORKSHIRE

GEOLOGICAL AND POLYTECHNIC SOCIETY.

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1903.

THE GLACIER LAKES OF CLEVELAND.

BY PERCY FRY KENDALL, F.G.S.,

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In pre-glacial times Yorkshire seems to have stood at a considerably greater elevation than at present, for drift-filled valleys have been proved to descend in many places below sea-level. In the great valley between Newcastle and Doncaster there is an old drift-filled hollow, which at Gateshead is 140 feet below O.D. South of the Tees borings reveal a great depth of drift until the line joining Northallerton and Bedale is reached, where it becomes thin over an old watershed, but thickens again southwards, and the rock floor of the valley is 74 feet below O.D. at Cawood, and 170 feet at Barnby Dun, near Doncaster. In the Vale of Pickering drift deposits reach a thickness of 107 feet, and the rock floor from Filey to Malton lies below sea-level. This evidence points to a long period of pre-glacial elevation, but, on the other hand, borings in Holderness show a plain of marine erosion, with blown sand banked against the old chalk cliff, at practically the present level.

Generally over the coast region of Yorkshire two boulder clays have been identified. An upper clay, reddish and almost devoid of boulders, and a lower clay, which is bluish, and contains many erratics. The erratics in the Cleveland area may be grouped into three divisions, according to the place of origin :—

I.—Western Group.

South-western Scotland.
Lake District and Vale of Eden.
Teesdale and Pennine Chain.

II.—Northern Group.

South-eastern Scotland and the Cheviots.*
Eastern Durham.

III.—Eastern Group.

Christiania region.
Gulf of Bothnia.
Denmark, or Bed of North Sea.

Drift deposits completely surround the Cleveland area, and extend along the Vale of Pickering and Eskdale, but except on the north they only fringe the hill country. All along the Cleveland escarpment south of Stokesley drift is found continuously up to 400 feet, but in embayments it rises to 800 feet. In the Lockwood Hills a spread of gravel forms a capping at 867 feet, and further east the drift boundary varies slightly above and below the 800 contour-line. From Stonegate eastward the drift crosses the watershed in an almost continuous sheet as far as Whitby. From Robin Hood's Bay southwards the drift declines gradually to 600 feet at Seamer, fringing the front of the moorlands. but not extending down the gentle

* In my paper in the Q.J.G.S., Vol. LVIII., I remark (p. 565) that "the immense abundance of Cheviot volcanic rocks has only within the last three or four years been fully recognised by geologists in Yorkshire." It is right that I should add that their abundance in our drift deposits was fully demonstrated by one geologist, namely, the Rev. John Hawell, in 1887, who reported upon some 365 boulders, a large proportion of which were derived from the Cheviots.

westerly slopes. In the Vale of Pickering these deposits do not rise above 350 feet, and at the western end appear to be composed entirely of local rocks.

Along the escarpments overlooking the Vale of York drift does not occur much above 600 feet. Southwards it declines in elevation, and may be said to terminate in the two fine moraines of York and Escrick.

Glacial striæ have been found near Saltburn running N.W. and S.E., and at Roker, near Sunderland, from E.N.E. At Filey striæ have been recorded striking from N. 20° E., and N. 24° E., at Bayness (R.H. Bay) due N., and at Sandsend N. 35° W.

The Ice-Sheets.

There do not appear to be any evidences of the presence of the sea in the Cleveland area during the Glacial Period. The occurrence of shells, chiefly fragmentary, is most probably due to the invasion of the country by the edge of an ice-sheet, which advanced on to the land after traversing a sea-floor strewn with shell-banks. Profs. Garwood and Gregory's observations on the Ivory Gate Glacier have dissipated in a decisive way the objections against the possibility of a glacier transporting marine shells from deposits over which it passes, and the same observers have shown that materials thus picked up by a glacier can be transported to a higher level than the bed from which they were derived.

The evidence obtained in the district proves that we have to do with three great ice-sheets moving on the Cleveland area and combining in its glaciation.

I.—*The Western Sheet.*—This seems to have been the first to reach Cleveland. At this time the Irish Sea basin was filled with ice, forming a sea of ice which sent off a great glacier up the Solway, which, being joined by a glacier from the Southern uplands of Scotland, and by another from the Lake District, filled the Vale of Eden to overflowing. One immense ice-stream overflowed the Tyne watershed and invaded Northumberland, whilst another great glacier crossed by Stainmoor Pass into Teesdale, where it was joined by the Teesdale ice. This great ice-stream passed down Teesdale to the coast, and perhaps left the "rough ground" off Teesmouth as its terminal moraine. This movement would account for the striæ near Saltburn and the general west-to-east transport of local material associated with the Lower Boulder Clay. Subsequently the advancing Scotch and Scandinavian ice-sheets blocked the way of the Western ice seawards. Weardale being filled with ice made a northern escape impossible, and so the Teesdale stream turned southwards and invaded the Vale of York. It passed over the Northallerton watershed, rose high against the flanks of the Cleveland, Hambledon, and Howardian Hills, received a great tributary from the Ure, and probably another from the Swale, and passed down the valley as far as York, in the neighbourhood of which it laid down two well-marked moraines.

II.—*The Northern Sheet.*—The ice of the Scottish Lowlands accumulating in the Tweed valley, instead of pursuing a direct course to the sea at Berwick, at one stage turned sharply round the projecting end of the Cheviots and took a course almost southwards. The pressure of the Scandinavian ice-sheet seems to have been the overmastering cause that produced this strange deflection. This Scottish glacier, reinforced by Cheviot ice and the glaciers of the Tyne and Wear valleys, swept across Northumberland seawards, but was again pressed inland over the Durham coast, producing the Roker striations.

III.—*The Scandinavian Sheet.*—A great sea of ice, originating in Scandinavia, seems at this time to have filled the North Sea basin, and to have begun to press strongly on our northern coast. The impact of this sheet seems to have taken place from north to south, the Scottish ice feeling its pressure first and being forced westwards over the Clyde watershed into the Irish sea. Then the Tweed-Cheviot stream was diverted inland, and pressure was brought to bear on the Teesdale glacier. By this progressive movement southwards the Scotch-Cheviot ice was pressed in upon the northern face of Cleveland, the Tees ice-stream was diverted into the Vale of York, and the great mass of western boulders deposited off Teesmouth was spread down the Yorkshire coast mixed with Scottish and Scandinavian erratics. This route is indicated by the consistent series of striæ observed along the Yorkshire coast.

At the close of the Glacial Period the recession of these ice-sheets took place in regular order from south to north, the shrinkage of the Scottish and Scandinavian sheets northwards and eastwards being accompanied by a recession of the Tees ice to the west. The river mouths were thus in turn freed from obstruction, and resumed their normal drainage. A noteworthy exception to this rule seems to have been the persistence of a lobe of ice overriding the northern Cleveland watershed into Eskdale, after the mouth of the Esk was free from ice.

Fig. 1.

MAP OF THE MÄRJELEN SEE.

Glacier-Lakes.

Whenever a glacier or ice-sheet advances against or across the general slope of a country which is not occupied by ice, there will be a tendency to impound the natural drainage and to produce lakes.

The Alps furnish few examples of such lakes, as they are best developed where the relief of the country is low and the ice-streams are large. The Märjelen See (Fig. 1), in the Bernese Oberland, is the best-known Alpine example.

Norway, with its more extensive ice-fields, furnishes numerous and varied examples, but it is to the gigantic glaciers of Arctic America and the ice-sheet of Greenland that we must look for our best illustrations of this class of phenomena. These great ice-floods must, in the nature of things, more frequently oppose and impound the drainage of the ice-free country than could be the case with greatly-crevassed glaciers flowing for a few miles down steep mountain valleys.

An interesting chain of lakes is held up in the Chaix Hills by the ice-stress of the Malaspina Glacier, and the great ice-sheet of Grinnel Land sustains marginal lakes of large size; but it is around the lobes of the Greenland Ice-cap that they are to be found in the greatest number and perfection.

It is only natural, therefore, to expect that proofs would be forthcoming that glacier lakes of Pleistocene age had prevailed over areas extensive in proportion to the great magnitude of the ice-sheets. The first of such lakes to be identified was the gigantic Lake Agassiz in North America, the waters of which covered an area of more than one hundred thousand square miles,* and lesser lakes have since been described in various parts of North America. Similar glacier lakes have been recognised in the valley of the Black Cart, south of Glasgow, in the valley of the Tweed, in Glen Roy, and in the Vale of Pickering.

The evidences by which ancient glacier lakes can be recognised are mainly four:—(1) Beaches; (2) Deltas; (3) Floor Deposits; and (4) Overflow Channels.

(1) *Beaches.*—The occurrence of beach lines, whether consisting of detrital accumulations or of mere shore-scarps, is clear proof of the former presence of standing water; but no absolute proof, apart from included organisms, can be adduced to show whether it was sea or fresh water. There is a general

* In the paper in the Q.J.G.S. I stated that the area of Lake Agassiz was 500,000 square miles. This was a mistake; the figure there given was the area of ice-free country draining into the lake.

rarity of beach deposits in Cleveland, and no well-defined example. Shore-scarps are common, but of limited extent. The reasons for this deficiency appear to be (*a*) the rapid lowering of the water-level, and (*b*) the want of sufficient beach-forming material. The overflows of the Cleveland lakes were over Jurassic rocks, mostly soft shales; hence they were cut down swiftly, and little or no beach formation resulted.

(2) *Deltas.*—When a stream carrying sand or gravel enters standing water, the detrital materials are cast down in the form of a fan, the surface of which is just below the high water or flood-level. If debouching into the sea, the fan shelves off into the deep with a continuous slope, while a lake delta usually terminates with an abrupt face. In the Cleveland area such deltas are rarely seen, but some examples exist, especially in the valley of the Esk. They occasionally exhibit the fan-like form and steep scarp of lacustrine deltas, but more often they are simply patches of current-bedded sand and gravel occurring isolated at the beach-level where some stream has debouched, generally the overflow from another lake.

(3) *Floor Deposits.*—A river flowing from a glacier is rendered milky-white by the extremely fine sediment which it carries in suspension. When such a river enters a lake a delta of the coarser detritus will first be thrown down, but the finer particles will be floated far out into the lake and form a finely laminated mud or warp. This deposit will conform itself to the undulating floor of the lake, which it will cover like a mantle. With an absence of vegetation on the lake bottom, such muds may be expected to display regular laminations, which, being parallel to the underlying surface, may be highly inclined.

These characteristics are frequently displayed in the warp-clays of Yorkshire. A section at Danby, in Upper Eskdale (Fig.2), contains a deposit indicative of lacustrine origin. Under red and blue clays is a leaf-clay, which contains interlaminations of very fine sand. A specimen showed 24 layers to the inch, each of which was found to consist of eight exceedingly fine laminations, making about 200 laminæ to the inch.

(4) *Overflow Channels.*—When an ice-sheet or glacier obstructs the drainage of a country, the water is impounded so as

to form a lake. This lake may find an escape, either through or over the ice, in which case the only records of the lake on the retreat of the glacier will be beaches, deltas, or lacustrine deposits. But if the lake drain by an overflow across a col, or spur, the water will cut a channel, which will remain a permanent record of the lake after the retreat of the ice-barrier. Such an overflow channel may be either "anomalous" or "deserted." If the ice-dam persist for a sufficient length of time, or if a moraine of sufficient height be left, the excavation of this notch will continue until the lake be completely drained, and the channel will carry the normal drainage of the country. There will then be left an anomalous gorge disproportionately narrow for the stream it contains, whilst the original line of drainage below the moraine

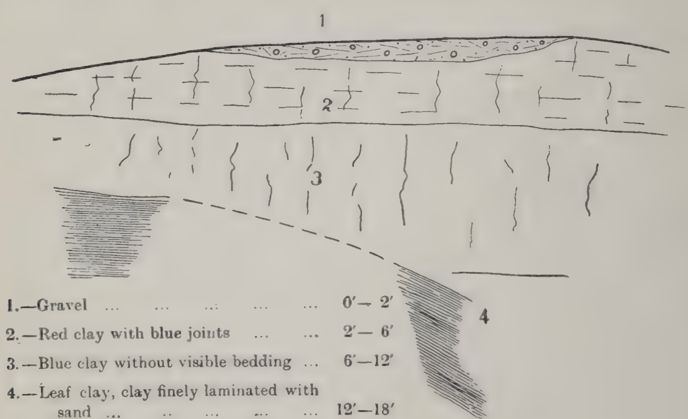


Fig. 2.

SECTION AT DANBY BRICK AND TILE WORKS.

is left as a deserted valley. Such a gorge is that of the River Nidd, near Knaresborough. If, however, on the retreat of the ice, the old line of drainage is resumed, the temporary overflow channel will be abandoned, and thereafter will carry only such small amount of drainage as belongs to its own very limited catchment, sometimes none at all. Then we shall have a deserted overflow channel.

The anomalous overflow valleys in the Cleveland area are simple in character and easy of recognition. The deserted channels, having remained practically unchanged from the time of the departure of the ice, with all their characteristics unimpaired, are of singular interest and demand careful consideration. They are among the most impressive memorials of the Ice Age that our country contains.

The Deserted Overflow Channels.

These channels conform to four principal types in regard to position :—

(1) *Direct Overflows.*—These trench the watershed of a glacier-lake in such a way that the drainage takes place directly away from the ice-front. Usually only the lowest col of a given watershed is trenched. except where the ice-front approached very near the watershed. 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.

(2) *Severed Spurs.*—When the ice-sheet has impounded the waters of a valley at such an elevation that a direct overflow is not available, the lake will discharge its waters by a channel cut on the outer face of a spur along or at least parallel to the edge of the ice. During the retreat of the glacier a series of these notches may be cut on the face of a spur, each representing a halt in the retreat.

(3) *Marginal Overflows.*—These are at first merely shelves cut in the hillside, and developed subsequently into actual gorges. Some marginal overflows cease to operate before reaching the "gorge stage," and in the Cleveland area every stage is represented.

In some instances a marginal overflow had its iceward side composed of moraine, and in other instances entirely of ice. The marginal overflows and severed spurs often are arranged in series, which may be of two kinds—the aligned sequence and the parallel sequence.

An aligned sequence is one in which several valleys may be obstructed, and drain from one to another by severed spurs, until free escape is offered either laterally or directly. These aligned series will all have their fall in the same direction, and the lake-levels will be successively lower along the series until the main escape is reached.

In studying the severed spurs, with their variants, in an aligned sequence, no surprise need be felt if two spurs are severed, while an intervening one of equal prominence remains intact. The ice-margin has commonly been very sinuous, and even lobate, and a lakelet might stretch across two valleys or more. Very often it has happened that an aligned sequence has been modified by a differential retreat of the ice-margin, causing one lake to persist longer than another. Thus a retreat of the ice-front near the lower end of a series may allow of a lateral escape and thus throw some intermediate channel out of operation, while its neighbours, above and below, continue to fulfil their functions and to cut lower.

The other kind of serial development I have termed a parallel sequence. These series, which frequently have also an alignment, consist of repeated trenchings of the same spur by parallel overflows. They are produced by an intermittent retreat of the ice-front, uncovering successively lower slopes of a hillside. It is satisfactory in these cases to find that the level at which each overflow commences to be cut is below the intake-level of its antecedent.

(4) *In-and-out Channels.*—These are crescentic valleys excavated in the face of a hill by water flowing round a projecting lobe of ice.

These overflow channels display some striking peculiarities of form, which distinguish them from valleys of normal types.

The first feature that strikes the observer is their entire independence of the natural drainage. They cut across the natural watersheds, and frequently are deepest just where they pass through it. This feature it is which appears most decisively to point, not merely to obstructed drainage, but actually to the existence of bodies of standing water.

The fall of these overflow valleys is usually very small near the head and steepens rapidly down stream, a feature which is rarely observed in normal valleys. The small fall in the upper parts of these channels usually results in the accumulation of peat, and this often produces a drainage out at the top end which obscures the characteristics of the intake.

The transverse sections of the overflow valleys are very characteristic; they invariably exhibit exceedingly steep sides, and, where unmodified by subsequent stream-action, possess broad, flat floors. These features indicate rapid cutting by a large stream.

In a large valley of normal drainage the sinuosities of the valley bear little or no direct relation to the meanderings of the stream. But in these overflow channels the glacier stream fitted the valley so closely that the valley walls conform to the well-known relation of the banks of a stream to its bends, a steep bank on the outside of the bend, with a gentler slope on the inside. These features are well shown in the upper portion of Newton Dale.

Both the intake and the outfall of an overflow valley may end quite abruptly on a steep hillside, each end of the gorge being approximately at the level of the lake from which and to which the waters flowed. Subsequent cutting by a small stream may, however, render these points obscure.

A remarkable and striking effect of fluctuations in the edge of the ice, both in advances and retreats, is the production of deserted oxbows. These features are peculiar to marginal overflows, never occurring in direct overflows. When the advance of a lobe of ice causes an obstruction of a marginal outflow at one point, then an "in-and-out" crescentic valley is carved in the opposing hillside to connect the two portions of the valley. This new portion may be cut to such a depth as to become the permanent channel; the part obstructed by ice will therefore never come into use again, and on the withdrawal of the ice may appear as a high-level loop many feet above the functional channel. The more frequent case, however, is that in which the new channel has not been cut so deeply as the old one. In these instances, the withdrawal of the ice has reopened the main channel, and the new bow has been abandoned. The main valley continues to deepen so long as it is in use, and the abandoned bow will remain in singular isolation.

The last feature which it is necessary to mention is that these deserted channels, as well as the other type of anomalous valleys (those which now carry one of the main streams of the district), never, or very seldom, receive any considerable tributaries: and when they do, there are usually manifest signs that the tributaries belong to a drainage which was on a much higher plane before the time when the anomalous valley was cut.

The Cleveland Glacier-lakes.

When the great ice-sheets invaded the Cleveland area, the mouths of all the valleys opening on to the western, northern, and eastern slopes were blocked with ice and their natural drainage impounded, forming a series of glacier-lakes which drained from one to another and finally discharged their waters into Lake Pickering, the lowest of the series, the overflow of which passed through a gorge in the Howardian Hills, near Malton, into the Vale of York (Plate XIV.).

The glacier-lakes in the Cleveland area may be divided into four groups :—

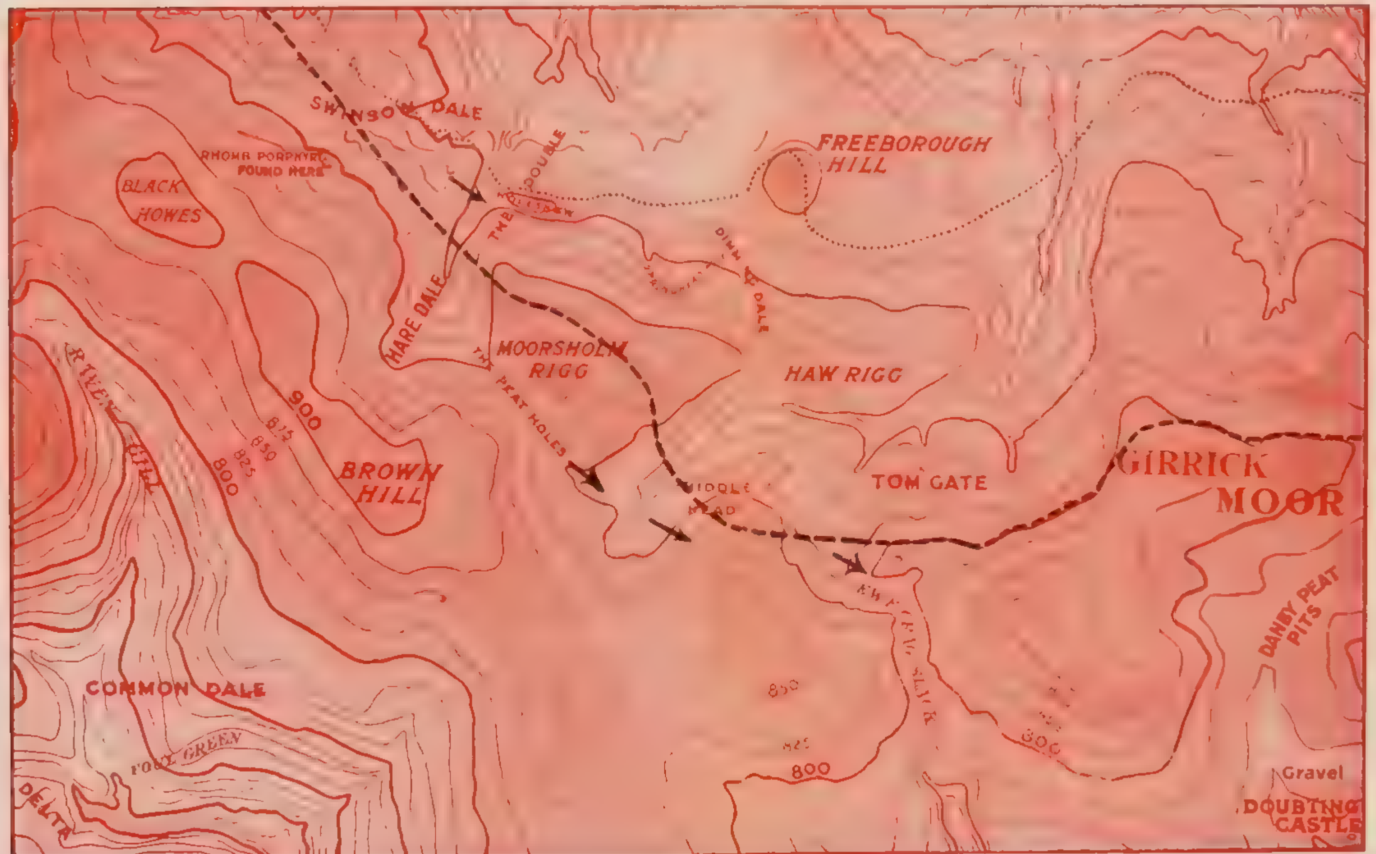
(1) The North-western Lakes.
(2) The Eskdale Series.
(3) The Coast Lakes.
(4) Lake Pickering.

(1) The North-western Lakes.

At the period of most extensive glaciation a great press of ice bore in on the northern face of the Cleveland Hills. Denudation had at the western end swept one side of the Cleveland anticlinal away, and left in its place a deep triangular recess overlooked by a serrated escarpment, which exposed sections of a number of beheaded valleys. The distribution of erratics and other signs show that at the maximum extension of the ice an overflow may have taken place by every notch of the escarpment, but of only three of these can this be positively asserted.

Scugdale Lake.—At the western end of the escarpment, near Whorlton, is Scugdale, a valley hemmed in by lofty ridges,

..... Approximate position of the ice front when the upper channel of the "Double" was being cut
— — — — " " " " at the maximum extension.
⟶ Direction of extra-morainic overflow.



RELIEF MAP OF THE COUNTRY BETWEEN COMMONDALE AND DOUBTING CASTLE.

SCALE: 2 inches to 1 mile.

rising to upwards of 1,000 feet except at one point, where a gap occurs in a stony ridge on the western side of the valley. Here a narrow, sharply-cut notch breaks through the 1,000-foot contour, and forms the intake of a deep channel, Holy Well Gill, which has all the characteristics of a lake-overflow. When this overflow was in operation the valley must have been choked with ice and the lake formed by the drainage of the ice-sheet small. A little to the west at the same period a small lakelet must have been formed in a minor recess above Scarth Wood, the overflow from which cut a well-marked notch through the watershed into the valley leading down to Osmotherley, but this was of short duration, a slight recession of the ice opening a lower gap, the fault-valley of Scarth Nick, which then carried off the waters of this and Scugdale Lake which had become united to it.

Scarth Nick is a fine example of an overflow; the valley is 100 feet deep, with a breadth of only about 150 yards at the top of the cutting, narrowing to about 30 yards, or less, at the bottom. The floor is flat, and contains much peat. Near its confluence with Crabdale, a valley of normal shape, there is an immense accumulation of gravel standing as a mound in the middle of the valley. Lake Scugdale was, at its maximum, about 400 feet deep. When Scarth Nick was opened, the level fell nearly 200 feet, but the area of the lake was not greatly affected, for the hillslopes are steep, and the recession of the ice-front would compensate for the loss.

Ingleby Greenhow Lake.—The re-entrant angle of the Cleveland escarpment at the eastern end is breached by a splendid overflow-channel (Plate XIV.). It is a deep, square-cut notch, carrying no stream now, and is a simple example of a direct overflow. It probably drained a considerable part of the ice-margin for a long period by way of Bilsdale and Ryedale into Lake Pickering. This overflow was recognised by the Rev. John Hawell before my survey had extended so far westward.

Kildale Lake.—The western outlet of Kildale is obstructed by a moraine which rises 100 feet above the floor of the valley. The upper part of the valley is largely occupied with drift deposits, consisting mainly of sand and gravel, which cover its central part, and boulder clay along the margins. The head of Kildale contracts in a marked fashion before the point of entry of the Leven is reached, and then expands to the watershed at West Bank. The watershed is broad and flat, and is occupied by an extensive bed of peat. A great overflow into Eskdale must have taken place here in glacial times. At the higher levels of Lake Eskdale (725 to 715 feet) there would be a depth of 150 feet of water over the pass, and Kildale and Eskdale would form one long lake (Plate XIV.). As the eastern outlets of Lake Eskdale were opened one by one the level of the lake fell until a strong stream flowed through the channel at West Bank. The course of this overflow was at once checked by the tranquil waters of Lake Eskdale and the coarse detritus was thrown down as a delta. This produced the mass of gravel stretching down into Commondale, and forming a well-defined plateau at 550 to 575 feet O.D., corresponding with the Moss Swang outlet of Lake Eskdale. The gravel extends for two miles down Eskdale to Hell Hole, where it forms a flattened mass at an altitude of between 525 and 550 feet. This would indicate a further stage in the lowering of Lake Eskdale, but this second delta is probably due to a redistribution of part of the Commondale delta, when the lowering of the lake allowed a free stream to denude it. A third stage is, perhaps, represented by a gravel flat extending to the east of the Howe at Danby, at an altitude just above 500 feet.

Bold Venture Lake.—East of Hutton, one of the heads of Sleddale, Bold Venture, has a flat gap, about a quarter of a mile wide, just below the 800-foot contour (Plate XIV.). On the eastern side of the gap are abundant erratics, including Cheviot porphyrites, and the broad gap itself is encumbered with gravelly material cut into a close-set series of mounds with their long axes running down the valley. To the south of this drift barrier there is a great tract of peat. Some overflow must have gone on here, both from the drainage of the ice and also from a temporary lake in its advance and retreat, but no definite channel can be traced.

Moorsholm Lakes.—Above Lockwood and Moorsholm the ice-sheet impounded the drainage of a considerable area, and an

Photographed by Godfrey Bingley, Leeds.

VIEW LOOKING UP EWE CRAG SLACK.

(The white objects are boulders of grit.)

Photographed by Godfrey Bingley, Leeds

VIEW LOOKING DOWN EWE CRAG SLACK.

(The bluff on the right is the feature shown on the left in the upper photograph.)

L-shaped lake or series of lakelets was formed. The drift in this area becomes thin at 600 feet and disappears altogether at 850 feet. Moorsholm Lake was of long duration, for its overflow. "Peat Holes," behind the spur of Moorsholm Rigg (Plate I.), is of considerable magnitude. It commenced to be eroded about 825 feet, and continued to be cut down almost to the 800-foot contour. A series of small parallel marginal channels round Middle Heads, the next spur to the eastward, would bring the overflow water from Peat Holes to the entrance of a fine channel, Ewe Crag Slack (Plate II.). This is a direct overflow into Eskdale, having the form of a great winding valley with its intake directed westward but soon making a sharp turn to the south. The first half-mile of the Slack is slight in inclination and occupied by a deep accumulation of peat, but it rapidly steepens after cutting through a thick bed of hard grit, and enters the valley of Black Beck (Haw-Rigg Slack), a normal moorland stream-course. This overflow first came into operation at an elevation of about 800 feet, and it was cut down to about 750 feet across the watershed. The usual features of the meanders of overflow-gorges are seen in this valley, and there are lofty crags along the west side for a considerable distance. Near the confluence with Black Beck is a great mass of gravel, which has yielded many erratics, including Cheviot porphyrites and one rhomb-porphyry. This gravel-mass then spreads out into Eskdale, forming two distinct terraces at the 600-foot and 575-foot contours, representing two halts in the lowering of Lake Eskdale, the lower one agreeing in height with the Commondale delta-plateau.

A period of rather rapid retreat of the ice-margin caused the desertion of the Ewe Crag channel (Plate I.), and the drainage was conveyed by a series of marginal channels (Plates I. and IV.) to another great direct overflow at Stonegate, four miles to the east. Along the edge of the lobe of ice that had overridden the northern watershed and formed a moraine spanning Eskdale at Lealholm (Plate III.), a deep overflow channel was initiated running down the Stonegate Valley. This channel, upon the retreat of the ice from the Moorsholm watershed, took the whole drainage of the Moorsholm lakes eastward. Hardale

Slack, an immense trench cut in the plateau of Roxby Old Moor, was the first channel for this overflow. A second, and much greater intake, Tranmire Slack, comes directly through the plateau from the north-west; and a third, Moses Slack, of lesser size, from the north. These two latter orignated as mere gutters to carry off the water from the ice-front when it was at the watershed. The Tranmire channel is connected with the Moorsholm Lake by a series of parallel aligned channels of great complexity.

At Stanghow (Plate V.), six miles to the east, there is a well-defined overflow channel cutting the 625 contour, which appears to be the lowest channel possessing an easterly drainage in the north of the Cleveland Hills. Close to this Stanghow channel, and a few feet lower, is another valley, Bushy Dale, with a steep fall *westward*. This appears to have been connected with channels leading to the Vale of York, which was the only way of escape for the drainage of the ice along the northern escarpment in the closing stages of its retreat.

At the lower end of Tranmire Slack, from its confluence with Hardale Slack, the valley is excavated through a flattened floor of gravel, which forms a notable pair of terraces. The lower terrace about the village of Stonegate is a shelf of hard sandstone in which the stream has cut a splendid gorge, but a little further up a series of derelict railway cuttings show 30 feet of very coarse gravelly clay, containing so many fragments of Upper Liassic shale that in parts they make up a large proportion of the mass. Blocks of Jurassic sandstone are abundant, and many foreign boulders. The most noteworthy fact is the comparative rarity of Carboniferous rocks, and the abundance of Magnesian Limestone with botryoidal and other concretionary structures. These terraces were produced as a kind of marginal delta between the hillside on the west and the ice-margin on the east of the valley.

(2) The Eskdale Series of Lakes.

The great overflows from Kildale and the Northern Lakes, with their related delta plateaux and the laminated warp of Danby, point to the existence of a great lake in Eskdale, which,

Approximate position of ice-margin at stage of retreat represented by the overflows from the Hutton Mulgrave Amphitheatre
at the stage of maximum extension

RELIEF MAP OF THE NORTHERN CLEVELAND WATERSHED, BETWEEN DANBY BEACON AND KEMPSTON RIGG.

SCALE: Slightly less than 2 inches to 1 mile.

at its maximum, reached the 725-foot contour (Fig. 3). This lake was formed by a lobe of ice which pushed over the

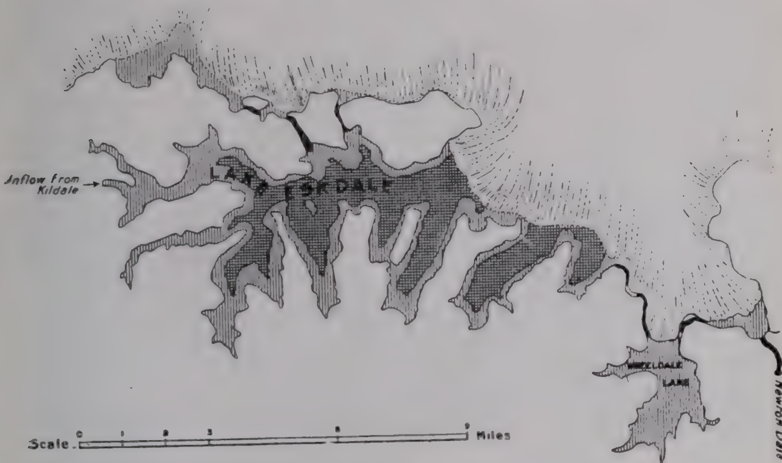


Fig. 3.

MAP OF THE ESKDALE SYSTEM OF LAKES AT THE LEVELS CORRESPONDING WITH THE LADY BRIDGE SLACK AND MOSS SWANG OVERFLOWS.

northern watershed and dammed Eskdale at Lealholm, laying down a moraine entirely across the valley. On the southern side of Eskdale drift is found up to altitudes of 700 feet, and a great morainic ridge, 100 feet above the valley bottom, runs across Glaisdale. The Egton Grange valley is also closed by a similar morainic barrier, and the whole formed, at the maximum extension of the ice, a lake eleven miles long, not less than 400 feet deep, and with ramifications up all the principal tributary valleys. These conclusions are confirmed in a very definite manner by a splendid series of overflow channels, which reveal the movements of the ice with great exactness. The first of these is a great trench, deepening and falling towards the south, which cuts across the edge of Murk-Mire Moor (Plate VI.). The sill of the intake is at 714 feet, and the channel extends for a mile and a half as a deep groove of characteristic section, filled with moss and swamp. After this stretch of complete trough the channel is continued for another mile to Hazel Head by a marginal channel, which for the greater part of the distance is a mere shelf lacking an ice-ward retaining wall, but in some places that function is performed by some gravel mounds. The shelf runs out and disappears near the Hollins, in Wheeldale, just below the 675-foot contour, and as it fails to indent the 650-foot contour it seems clear that it reached the waters of a lake. Where the overflow terminates a mass of gravel obstructs the valley of West Beck. Between the West Beck Valley and the valley of Eller Beck there stands forward a bold spur, Two Howes Rigg, against which the ice must have abutted, ponding up the drainage of West Beck (Fig. 4), for there is a beautiful

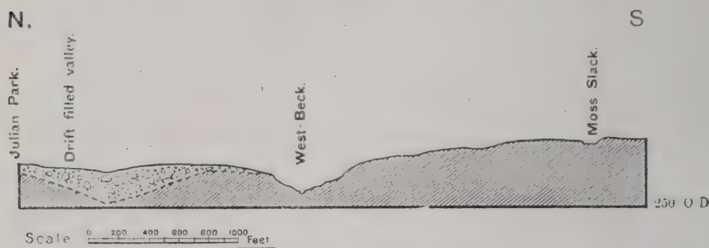


Fig. 4.

SECTION FROM JULIAN PARK TO TWO HOWES RIGG.

marginal overflow Moss Slack, cutting round the shoulder of the hill, and just getting through the 675-foot contour. Thus we have evidence that at the maximum extension of the ice Lake Eskdale, drained by the Murk-Mire Moor channel into Lake Wheeldale, which stood at an altitude of 675 feet, was three miles long and 225 feet deep. Lake Wheeldale drained by Moss Slack at 675 feet into a small lake in the Eller Beck Valley, which would have an extreme altitude of 650 feet, as determined by the overflow at Fen Bogs into Newtondale (Plate VI.).

The period of occupation of the Hollins Channel was very brief, and a slight retreat of the ice-front caused the production of the much more important channel consisting of two segments—Lady-Bridge Slack and Purse-Dyke Slack.

A further retreat of the Goathland lobe of the ice-sheet had for its first effect the withdrawal of the margin from Purse-

Photographed by Arthur Stather, Hull.

VIEW OF THE "DOUBLE." HARE DALE.

Photographed by Arthur Stather, Hull

VIEW LOOKING UP HOLE SKEW, HARE DALE.

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

Moor, whereby a "lateral escape" was opened in the Murk-Mire overflow, so that the distal portion, Purse-Dyke Slack, was abandoned, and the outfall of the proximal half, Lady-Bridge Slack, was cut down below the 700-foot contour. This did not affect the Moss Slack overflow. The next shrinkage was a much more considerable one—the ice-margin withdrawing to a position about a quarter of a mile from the Murk-Mire Moor channel and parallel to it, and a new channel was commenced at the 675-foot contour. The channel ran round the edge of the moorland, and for a long distance was bounded on one side by ice.

Its continuity was interrupted across the middle of its course by the natural valley draining the moorlands, known as Oakly Beck, so that this, like the higher channel, was in two segments—one, the more northerly, Moss Swang, and the southerly, Randay-Mere Valley (Plate VII.).

The next shrinkage took place when Lake Eskdale was lowered by erosion of the overflow at Moss Swang to about 625 feet. This opened a low gap in the side of the channel at Castle Hill (Plate VII.), and led to the abandonment of the oxbow there. Another explanation of the relation of this oxbow to the main channel of Moss Swang is that the Moss-Swang overflow had been deeply cut and then closed by a temporary readvance of the ice prior to the formation of the Castle Hill loop. The main channel continued to be eroded, and the oxbow, a splendid example of an overflow, stands more than 50 feet above the main channel.

The last stage of ice-retreat traceable in this region is represented by a deepening and deviation of the Moss Swang channel, showing that the Randay-Mere segment was the first portion abandoned. This is clearly shown by the lower level of the Moss-Swang outlet, as compared with the Randay-Mere intake.

No overflows corresponding with these are to be found on the end of Two-Howes Rigg, and it is clear that the ice did not abut against that hillside at such an altitude as to maintain a barrier between Lake Wheeldale and Eller-Beck Lake. The two became continuous, and may now be called Goathland Lake. During the succession of events here described the Fen-Bogs outlet was being lowered, but at a diminished rate, due to the fact that the overflow had cut down to a bed of hard grit out of which the sill came to be formed.

By the recession of the ice and the cutting of these overflows, Lake Eskdale would be gradually lowered to the 525-foot contour, which is the level of the overflow at Fen Bogs (Plate VIII.). The watershed is here cut through by Newton Dale as a broad, flat-floored trench, more than 50 feet deep, with steep sides. The gorge is now carpeted with a considerable

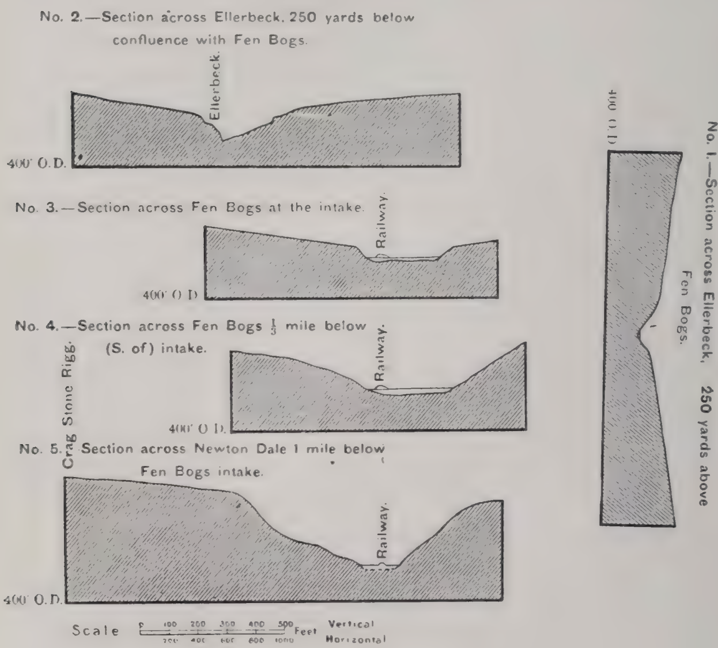


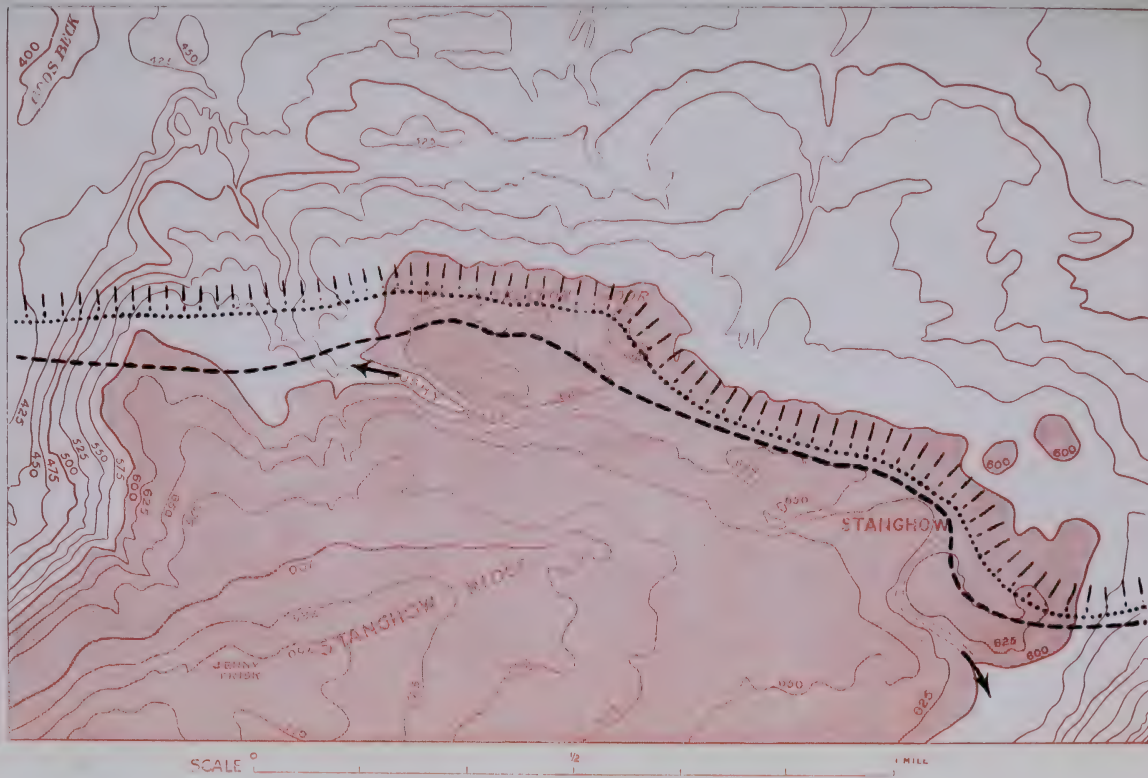
Fig. 5.

COMPARATIVE SERIES OF SECTIONS ACROSS THE VALLEY OF ELLER BECK AND NEWTON DALE.

thickness of peat, but borings have shown that the rock floor is almost exactly 525 feet above sea-level. Newton Dale is a fine gorge with very steep sides rising to 300 feet or more, and exhibiting a series of windings which show that the valley walls were the banks of the stream as well. Just to the north

⁝⁝⁝⁝⁝⁝⁝⁝⁝ Ice-margin at the beginning of the eastward drainage.

← → Direction of the extra-morainic drainage.



MAP OF THE COUNTRY ROUND STANGHOW.

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

of the head of Newton Dale it is joined by the valley of Eller Beck (Plate IX.) on its eastward side (Plate VIII.). Eller Beck flows in a normal valley until it reaches Newton Dale, when it turns sharply to the north and flows through a V-shaped valley to join the Murk Esk. A comparison of Eller Beck valley with the Fen Bogs channel (Fig. 5) shows that the latter is far too large to have been cut by such a stream as Eller Beck, and belongs to a type of channel wholly different from that which such a stream would produce.

CONTOUR MAP OF PICKERING DELTA

Fig. 6.

For two and a half miles of its upper course below Fen Bogs (Plate VIII.) there is no continuous stream, but bog with an occasional strip of running water. Newton Dale thus shows the characteristics of a true glacier-lake overflow. It must have carried a large stream during the time that all the drainage of Northern Cleveland and Eskdale Lake was being discharged over the col at Fen Bogs, and consistent with that is a great fan of delta deposits which, shelving out from the end of Newton Dale, occupies some square miles in what was then a lake in the Vale of Pickering (Fig. 6). This delta of coarse gravel is partly covered by the warp beds of the lake, showing that Newton Dale ceased to be an overflow before the close of the Glacial Period.

The sequence of events in Eskdale shows that the ice-sheet retreated so as to leave a channel of escape by the mouth of the Esk before the lobe of ice was withdrawn from the moraine at Lealholm, and this lobe seems to have persisted not only after the mouth of the Esk, but practically the whole coast-line of Yorkshire down as far as Scarborough, was free of ice. A series of channels excavated by lake overflows, some of which are still occupied by the River Esk, belong to this period. The highest of these channels is Wild Slack (Fig. 7), a small, but definite,

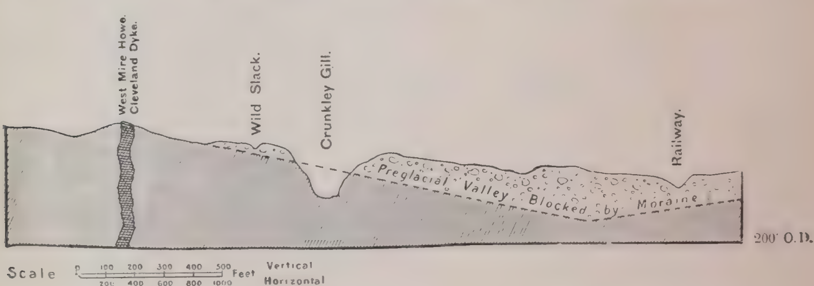


Fig. 7.

SECTION ACROSS CRUNKLEY GILL AND THE LEALHOLM MORAINE.

overflow, which cuts the southern limb of the Lealholm moraine immediately south of Crunkley Gill. It notches slightly the 525-foot contour, and dies out about the 500-foot contour.

A small shrinkage of the ice opened a slightly lower gap in the moraine on the site of Crunkley Gill, where a spur of rock was covered by about 50 feet of drift. A new notch was started here, and the level of Lake Eskdale was lowered from about 500 feet, the original level, down to 450 feet, when the outlet began to cut into live rock. By this time it had probably passed the critical level of the moraine, and any further withdrawal of

▬ ▬ ▬ Ice-margin at period of maximum extension (Moss Slack Stage).
· · · · · · · ,, ,, ,, 1st stage of retreat (Purse Dyke Slack Stage).
ıııııııııııı ,, ,, ,, 2nd ,, ,, ,, (Lady Bridge Slack and Randay Mere Stage).
o o o o o o ,, ,, ,, 3rd ,, ,, ,, (Moss Swang -Randay Mere Stage).
+ + + + + ,, ,, ,, period of re-advance (Castle Hill Stage).
—·—·— ,, ,, ,, 4th period of retreat (Moss Swang -Struntry Carr Stage.)

NORTH.

SOUTH.

RELIEF MAP OF THE COUNTRY BETWEEN FEN BOGS AND EGTON BRIDGE.

(The scale is a little less than 2 inches to a mile, and the distance from north to south is exactly 6 miles.)

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

the ice could not affect the position of the overflow. Subsequently, perhaps in post-Glacial times, the final drainage of Lake Eskdale was achieved, and the great gorge of Crunkley Gill, 125 feet deep, completed (Fig. 7).

About a mile below Crunkley Gill, the steep hillside on the south of Eskdale is excavated by a very perfect example of an "in-and-out" channel. Sunny-Brake Slack (Fig. 8), the channel

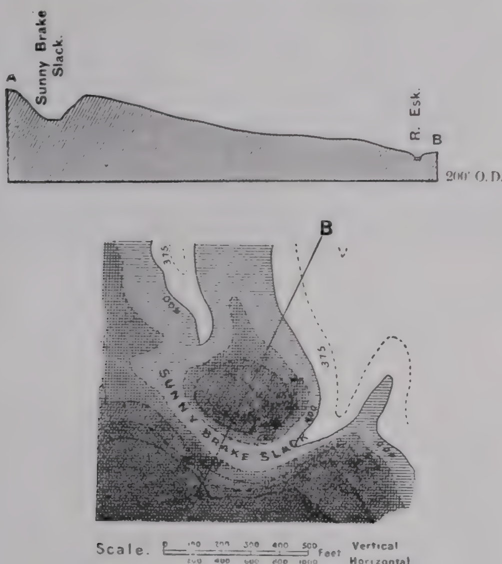


Fig. 8.

MAP AND SECTION OF SUNNY BRAKE SLACK "IN-AND-OUT."

in question, is about 75 feet deep, with sharply-cut sides and a broad peaty floor falling to the east. The excavation was commenced above the 475-foot contour, and it cuts through the 425 nearly to the 400-foot contour. The main Esk Valley here descends to 275 feet, and at the 475-foot contour it is three-quarters of a mile wide, so that it will hardly be believed that the post-Glacial denudation could have achieved all this; but besides this, it is not the habit of rivers to forsake a rock-gorge on account of the difficulty of cutting in it.

The levels show that the ice-barriers stood simultaneously here and at the gap in the Lealholm moraine, for the cutting commenced at Sunny Brake at a level above that at which the Lealholm gap would have been open. Between Crunkley Gill and Sunny Brake a narrow marginal lake probably extended, much of it more river than lake.

A third significant gorge occurs at Glaisdale, less than half a mile below Sunny Brake. Here the Esk has cut a deep gorge into the rock to evade a morainic obstruction, although the moraine is of less height (325 feet O.D.) than the top of the gorge, which is distant only 300 yards. (See map, Plate XIV.)

The three examples, Crunkley Gill, Sunny-Brake Slack, and Glaisdale, show that an ice-obstruction extended across Eskdale at the same time that a free fall for water could be obtained at the levels which I have indicated, namely, for Crunkley Gill, 500 down to 450 feet; Sunny Brake, 475 down to below 400 feet; and Glaisdale, about 350 down to 325 feet.

Where, now, was the actual escape southwards?

One of the peculiarities of the Fen Bog overflow is that it is the lowest outlet from Eskdale, saving only Whitby Harbour, and that appears to have been the actual outlet. This, of course, need not imply that the coast at Whitby was free from the edge of the ice, for the cutting of the gorge may have been merely commenced at this stage, and marine erosion on this coast has no doubt removed a strip a mile or two in breadth since the Glacial Period. But there must have been a free fall to the southward, and this can have been obtained only by low-level channels in a coast-tract since carried away, or by actual open water.

The stages of ice-retreat in Eskdale are indicated by a series of morainic ridges of sand and gravel that descend from the northern moors across Eskdale at Glaisdale, and a further chapter in the Glacial history of this district is very clearly recorded by a series of overflow channels cutting through the northern watershed above Egton Bridge.

The retreat of the ice from Eskdale carried the melting front, step by step, backward up the northern slopes of the Esk Valley, until it fell entirely behind the crest. It withdrew

Photographed by Godfrey Bingley, Leeds.

INTAKE OF THE CASTLE HILL OXBOW VIEWED FROM MOSS SWANG.

(The sill is 50 feet above the floor of the main valley.)

Photographed by Godfrey Bingley, Leeds.

RANDAY MERE VALLEY VIEWED FROM THE SOUTH.

similarly from the Stonegate Valley in an easterly direction, and halted on the watershed, where a series of gravelly mounds are seen with strongly-channelled fronts overlooking the valley. In the retreat many trenches were cut by streams flowing from the melting ice ; some of these, as the ice-front drew back behind the watershed, cut steadily backward through the crest, and produced a set of overflow channels for the discharge of a series of small lakelets formed along the margin of the ice.

Three true lake overflows cut the watershed more deeply. These are, in order from east to west :—(1) Middle-Carr Slack, which makes a slight trough through the watershed near Lady-Cross Gate, but deepens to a pronounced feature in its lower course. (2) Stonedale Slack, a very fine ravine which now cuts the crest in a very marked fashion. A curious cross-channel connects these two valleys near their head. The two channels probably were of brief occupation, and their strong development in their lower parts, as compared with the heads, is consistent with the view here adopted, that they were primarily channels carrying the direct drainage of the glacier. (3) The third overflow is of a very different type—it is a great gorge 30 to 40 feet deep, which forms a very conspicuous breach in the line of watershed at Barton "Howl." The overflowing stream commenced to cut at about 680 feet, and ceased at about 665. These, then, may be regarded as the approximate water-levels of a small lakelet on the iceward side of the watershed. This lakelet had a maximum area not exceeding three or four square miles.

The last evidence of constrained drainage in Eskdale that demands notice is the actual outlet of the River Esk at Whitby. The river here flows through a rock-gorge about 100 feet deep, and so narrow as to forbid the supposition that this was its ancient course. This was to the west of the town and into the sea at a point where the cliffs, entirely composed of drift, show a pre-glacial valley. The modern course may be either due to the obliteration of the old valley by glacial deposits, or may mean that the stream was compelled to take a course along the outer edge of the ice, and had cut the rock gorge sufficiently deep, before the ice was withdrawn, to render it the permanent line of drainage.

(3) The Coast Lakes.

The line of watershed extending from the head of Iburndale round Sneaton Low Moor marks the beginning of a drainage system displaying many remarkable anomalies. A narrow coast-strip of country, extending from Robin Hood's Bay on the north to Hunmanby on the south and varying in breadth from 100 yards up to a maximum of about three miles, drains in a general way down the normal slope of the land into the sea. (Plate XIV.). But, behind this, at a short distance, seldom more than three, and never more than six miles, there runs a great gorge which receives all the drainage of the hinterland and carries it away to the south, and finally westward, through the Vale of Pickering, into the Ouse and Humber drainage. Thus it is that streams, rising within two miles of the sea at Robin Hood's Bay or Peak, pass into a system which enters the sea at Spurn.

In the initiation of this drainage, the effects of an ice-sheet which shut the seaward ends of the valleys is clearly traceable, just as was the case in Northern Cleveland, but with this difference, that in the northern area the lake-overflows were rarely cut to so great a depth as permanently to deflect the larger drainage channels. On the eastern coast the ice invasion was not so extensive, and the overflows were all of the marginal type. Some of the cutting was over high and prominent watersheds, but more often existing drainage-lines were followed and deepened. Moreover, the effects were cumulative, as one aligned sequence remained in occupation for a long period, and an increasing volume of water was brought to bear upon just those regions where the greatest barriers were encountered, namely at Hackness and Suffield Moors. It will be further shown that at these two places the physical features of the country were such as to secure a stable position of the overflows during considerable oscillations of the ice-front, so that persistent cutting on one line of overflow would take place, instead of the excavation of a parallel series of successive channels such as occurred in other areas.

Iburndale Lake.—This lake, though standing isolated in a large measure, forms the first of the five series of lakes that

Photographed by Dr John L. Kirk

NEWTON DALE AT FEN BOGS, VIEWED FROM ELLER BECK.

The Stream in the foreground makes a sharp turn to the north and leaves the great trench untenanted.)

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

discharged their waters by the east coast route. Iburndale is a deep, rather narrow valley, forming a V both in plan and section. It opens northward into Eskdale at Sleights, and is separated from the Murk-Esk Valley on the west by Sleights Moor, a broad tract of Lower Estuarine grit, which forms a steep escarpment on the west, north, and east. This constitutes a watershed nowhere falling below 800 feet. On the east, Iburndale is enclosed by the high moorlands (of the same grit) of Ugglebarnby and Sneaton, which attain an elevation of 700 feet quite near to Eskdale; and this altitude, or a still greater one, is maintained nearly to the head of the valley.

Drift deposits of great thickness occur in the floor of the valley, and to a considerable height up its sides. On the advance of the northern ice-sheet a lake was formed in Iburndale, the overflow of which was by a gap in the eastern side of the valley, cutting through the 675-foot contour, but not descending below the 650-foot contour. From this gap a deep, peat-filled valley, Biller Howe Dale, of characteristic section, extends eastward into the Jugger Howe Beck drainage, which constitutes the true source of the River Derwent. At the upper and streamless end of this channel is an abandoned oxbow separated from the main channel by a small hill of solid rock (Plate XI.). At the maximum extension of the ice the watershed of Sneaton Moor was overridden, and the ice extended to the Iburndale overflow. In the stage of retreat the watershed was trenched by two well-marked lake-overflows, but now streamless where they cross the watershed, and containing a considerable depth of peat.

Robin Hood's Lakes.—The natural amphitheatre of Robin Hood's Bay is packed with boulder-clay in its lower parts, and an outer fringe of drift on the westerly moorlands consists of sand and gravel heaped up in large mounds. The whole of the pre-glacial drainage of this area probably centred on the Bay (Plate X.).

At the period of maximum extension the margin of the ice-sheet appears to have extended from the head of Iburndale along a west-to-east line to the great bend of Biller Howe Dale, and thence to have run in a southerly direction past the side of Biller Howe farmhouse, and on to the junction of a little nameless beck, south of "the Island," with Jugger Howe Beck. The margin is well defined along the whole line by the extension of the drift and pebbles, and by the occurrence of the marginal channel which carried the drainage from Lake Iburndale and the ice-free country within the watershed.

From the point where Biller Howe Dale makes a right-angled bend to the south, a series of three high-level channels can be traced running parallel with the great gorge which at present carries the scanty drainage of this area (Plate X.). These three are really not so much an aligned sequence as one channel, the course of which has been intersected by two modern streams. The third segment cuts across the spur called "The Island," and its lower course has been adopted by a modern stream forming a deep gorge at its confluence with Jugger Howe Beck.

The first segment runs behind Biller-Howe farmhouse, and it is a streamless gully of about 20 feet in visible depth, but is known to contain at least 15 feet of peat near the house. Its intake is seen as a notch in the skyline 100 feet above the floor of Biller-Howe Dale. The second segment is a moss-swamp forming a deep trench across Biller-Howe-Turf Rigg. The third, rather less sharply-cut, segment continues in accurate alignment across the spur called "The Island," and its lower course has been adopted by a modern stream, forming a rocky gorge 100 feet deep at its confluence with Jugger-Howe Beck.

Beyond this point, a breach was made in the watershed on Jugger-Howe Moor; this separated the Robin-Hood's Bay drainage from that of the Hellwath Burn, which now flows into the Derwent drainage, but formerly entered the sea near Burniston. The margin of the ice-sheet appears to have stood for a very short time at its farthest point of advance, then to have retreated rather rapidlyfor a time to a position about which it lingered for a very long period.

The first effect of the retreat appears to have been to produce a great sinuation of the ice-margin which withdrew from Biller-Howe Dale, and uncovered a large part of Sneaton Moor. A large channel, Grey-Heugh Slack, was now developed running along the

Photographed by Dr. John L. Kirk.

VIEW OF ELLER BECK AND FEN BOGS FROM THE NORTH-WEST.

Photographed by Dr. John L. Kirk.

VIEW LOOKING UP ELLER BECK FROM THE INTAKE OF NEWTON DALE.

western margin of theice-lobe from Fylingdales Moor to Biller-Howe-Dale Slack. This channel would carry off the water flowing from the ice-front, as well as that coming from the ice-free ground on Sneaton Moor. As the shrinkage of the ice progressed, a series of small shallow trenches were worn through the gravelly eastern banks of Grey-Heugh Slack by water from the ice-front. The best preserved of these is a small slack draining to the westward from Foulsike Farm.

The next phase of retreat initiated a line of drainage, second in importance in the Cleveland area only to the great Newton-Dale gorge; this is the valley, bearing different names in its parts, which I may call the Jugger-Howe Valley (Plate X.). The margin of the ice had withdrawn northward so as to lie upon, or entirely behind, the Sneaton-Moor watershed. The shrinkage to the east brought the edge of the ice along the line of the present Jugger-Howe Valley, which at that time, however, had no existence. A recess in the hills at the northern end produced by the valley of Kirk-Moor Beck now became a small lake receiving the water draining from Sneaton Moor by the two channels mentioned, and also from its own section of the ice-front. A marginal channel was then initiated, which wound along the edge of the ice to join the Biller-Howe-Dale overflow from Lake Iburndale. This new channel, Foulsike overflow, continued to operate for a long time, and its broad and steep-sided gorge, though containing a great thickness of peat, still shows a depth exceeding 75 feet. It opens out abruptly at its intake into the very dissimilar valley of Kirk-Moor Beck.

Simultaneously, perhaps, with the formation of this valley, or, possibly, of an earlier date, a magnificent channel was being excavated along the southern edge of the great Robin Hood's Bay amphitheatre near Stony-Marl Howes.

If the high ground south of Robin Hood's Bay was over-ridden by the ice-sheet, it was but for a short time, and the ice-front broke up into a sinuate outline. The lobe which was thrust into the upper bay would have a strong southerly component of its motion, which would cause it to stand well away from the escarpment at its north-westerly angle, and to press more closely against the precipitous slopes on the south and south-east. So that whilst there would be a considerable lake to discharge by the Foulsike overflow, there would be only space for a series of small narrow lakelets along the southern edge. These lakelets appear to have drained by a marginal channel trenching the face of the escarpment, which at last attained the depth of 70 feet, and the lower part of which is now occupied by Burn-Howe Beck (Plate XII.).

The recessed character of the grit escarpment brought about —as the ice-edge retreated—the formation of two other marginal lakes similar to that in the valley of Kirk-Moor Beck, and each of these had its own separate overflow channel cutting through the narrow watershed between the Robin-Hood's Bay drainage-slope and the great intercepting drain of Jugger-Howe Beck. These overflows doubtless originated in the channels produced by streams running directly off the ice-front itself as it slowly retreated.

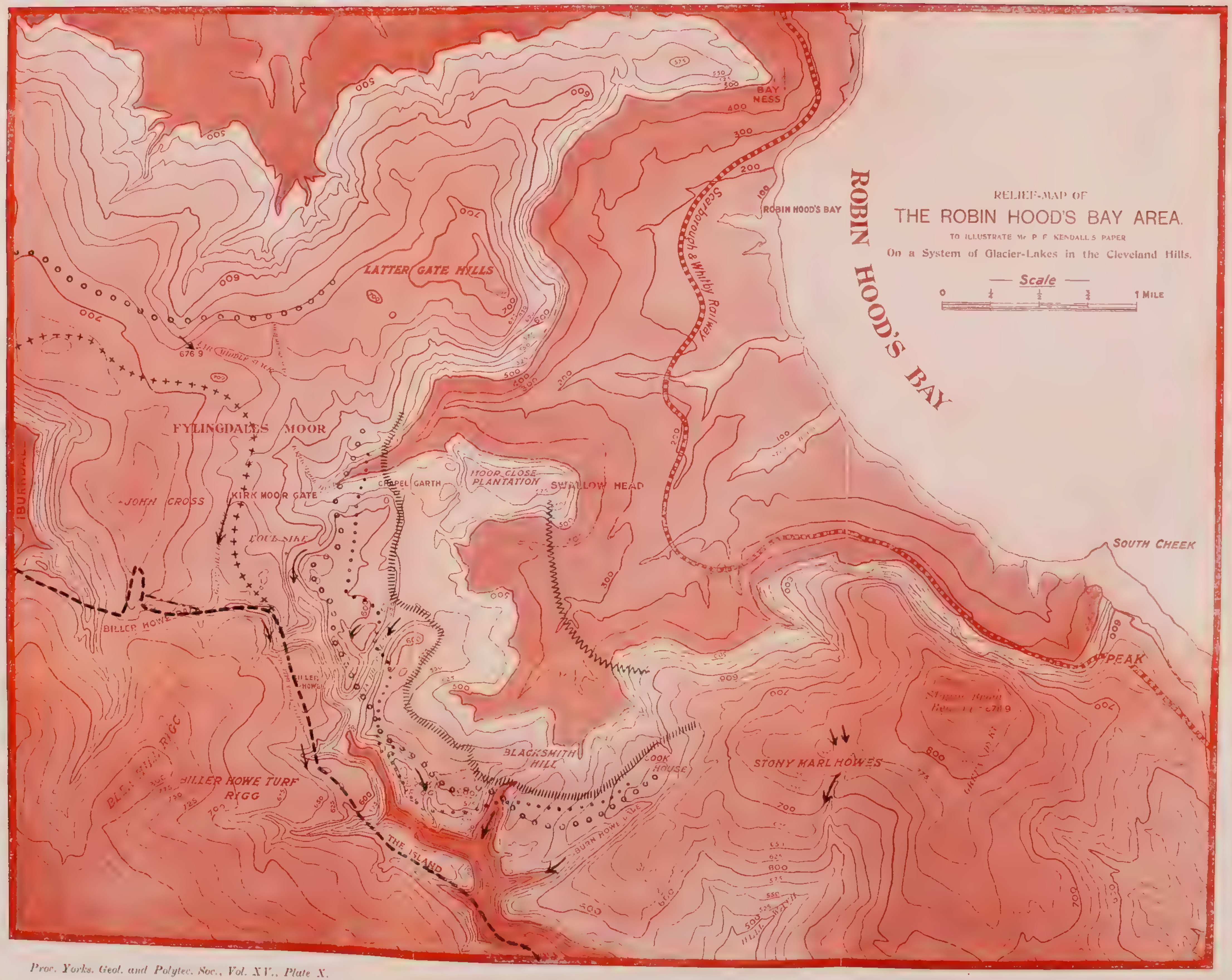
We now have the recess of Robin Hood's Bay occupied by three lakes—Kirk-Moor Lake on the north, Evan-Howe Lake in the centre, and Blacksmith-Hill Lake on the south.

The first of these was drained by Foulsike, and the second by a gigantic trench, Evan-Howe Slack, a valley about half a mile long, 100 yards wide across the floor, and nearly 100 feet deep.

During the shrinkage of the ice-lobe, the spur separating this lake from Kirk-Moor Lake to the northward was gradually uncovered, and, as the outlet of Evan-Howe Lake was lower than that of its neighbour, channels were cut across the lower parts of the spur whereby Kirk-Moor Lake was drained into Evan-Howe Lake. Therefore the Foulsike overflow now became functionless.

The southern lakelet was drained by the Blacksmith Hill overflow, which is a gorge almost exactly comparable in its dimensions with Evan-Howe Slack (Plate X.). It is about 1,000 yards long, and 50 to over 100 feet deep; a small stream occupies about two-thirds of its length. The intake is about 510 feet above O.D., but, as in all other large channels, there is a good deal of peat in the floor. The lake was probably, from its inception, fed by the drainage previously flowing down Burn-Howe Dale, which channel was consequently abandoned. The

Ice-margin at period of maximum extension.
,, ,, ,, ,, just before the maximum.
,, ,, ,, 1st stage of retreat (Grey Heugh Slack).
,, ,, ,, 2nd ,, ,, ,,
,, ,, ,, 3rd ,, ,, ,,
,, ,, ,, stage of re-advance (Brown Rigg and Evan Howe Slack closed).
,, ,, ,, 4th stage of retreat (Blacksmith Hill).



retreat of the ice-front threw the central and southern lakes into confluence, and as the Blacksmith Hill outlet was well below the intake of Evan Howe Slack, it took the whole drainage. When this happened, the ice stood for a short time against Swallow Head, the spur which bounded Kirk Moor Lake, for an overflow across the spur at Moor Close Plantation cuts at its lower end below the Evan Howe Slack intake.

A final recession of the ice opened a way for the waters round the seaward end of Peak, and, perhaps, by channels cut in the lower grounds, of which marine denudation has left no relic. During the whole of the period of the prevalence of these lakes it is probable that water was flowing out of Iburndale by way of Biller Howe Dale. No lower escape for the drainage of that valley, or of the outer face of the Sneaton Moors, existed, or could have existed, without leaving unmistakable traces. A fine example of a deserted oxbow runs behind Brown Rigg (Plate XI.), a bold hill dissected out of the moorland on the east side of Jugger Howe Beck. This oxbow channel is cut to a depth of from 60 to 70 feet, and is about half a mile in length. At both ends it opens out on to the precipitous wall of the Jugger Howe Valley, about 60 feet above its floor.

Harwood Dale Lake.—At the period of maximum extension the ice reached the edge of what is now Jugger Howe Beck. Before the Robin Hood's Bay watershed was breached Helwith Valley descended nearly to its present junction with Jugger Howe Beck, but the continuation of its course was what is now known as Castle Beck into Harwood Dale (Plate XII.).

When the ice advanced over this country it thrust across Castle Beck, diverting the drainage into a marginal channel, along which also poured the overflow from the Robin Hood's Bay area, and so a deep gorge was produced. A range of gravelly moraine now extends along the verge of Jugger Howe Beck, whose deep, narrow channel contrasts very strikingly with the broad, open valley of Castle Beck (Fig. 9), beside which it runs.

The course of Helwith and Jugger Howe Becks, if produced, follows the line of the great valley of West and East Syme, which extends from Harwood Dale to Burniston. This important valley is now occupied only by two diminutive streams which flow westward and eastward from a scarcely perceptible watershed across the middle of the valley. These cannot explain the valley in which they flow, and it seems best accounted for by the diversion of the Derwent by the ice-sheet through the glacial overflow of Hackness Gorge, but that previously the Derwent flowed down the Symes Valley to the sea at Burniston (Plate XIV.).

The explanation of this striking change in physical geography was the impounding of the drainage of Harwood Dale by an ice-dam across the Symes Valley which formed a lake, one arm of which stretched up the Jugger Howe Valley, and the other up Lownorth Valley, which found an overflow across a col, and

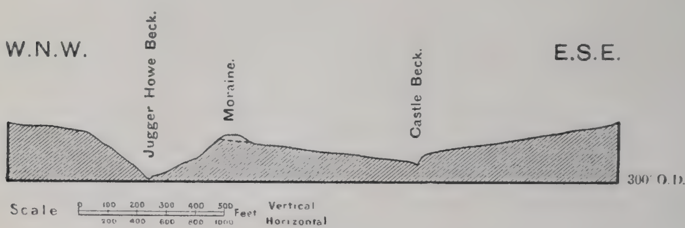


Fig. 9.

SECTION ACROSS JUGGER HOWE BECK AND CASTLE BECK, SHOWING THE MORAINE.

cut a steep gorge, Langdale, into the Hackness Lake. This gorge was cut so rapidly that before the retreat of the ice it was established as the line of permanent drainage, and any resumption of the old channel to Burniston was rendered impossible.

Lake Staintondale and Lake Hayburn.—The line of maximum ice-extension was not, however, long maintained. The margin appears to have been withdrawn from the line of Jugger Howe Beck rather rapidly, until it fell behind the water-parting of Pye Rigg and Hollow Rigg, beyond which the retreat became much more gradual, with long and frequent halts and some re-advances. Marginal lakes then were formed, and two are especially definite, one at the head of Staintondale and the other

Photographed by Godfrey Bingley, Leeds.

VIEW LOOKING UP BILLER HOWE DALE.

(The conical hill near the intake is isolated by the deserted oxbow.)

Photographed by Godfrey Bingley, Leeds.

BROWN RIGG VIEWED FROM THE WEST SIDE OF JUGGER HOWE BECK.

(The deserted oxbow is shown on the left of the ridge. Jugger Howe Beck in the foreground.)

at the head of Hayburn Beck. At first Lake Staintondale overflowed by the marginal channel of Pye Rigg Slack (Plate XII.) into Lake Hayburn. The retreat of the ice opened an outlet for Lake Staintondale by the Rudda Road col, at the same time that the waters of Lake Hayburn began to be discharged by Cowgate Slack (Fig. 10). A temporary retreat caused the cutting of Hardhurst Slack, but its intake was soon closed by a slight readvance of the ice, and Cowgate Slack again was brought into operation, and continued the main overflow for a long period. Meanwhile Lake Staintondale had cut through a second col in the intervening spur, forming the Tofta Road overflow, but further retreat threw this out of action, and the two lakes became confluent.

A further retreat of the ice eastward freed a col on the long spur bounding Lake Hayburn on the south, which was lower than the Cowgate intake, and a new channel, Ringing Keld overflow (Fig. 10), began to be formed along the edge of the ice. Further recession gave advantage to the new route, which developed

The horizontal line across each overflow marks the level of the intake, which is also given in figures.

Fig. 10.

SECTION ALONG THE WATERSHED FROM COWGATE SLACK TO HAYBURN WYKE STATION (NEWLANDS DALE).

into a large and deep valley abruptly terminating to the south at 400 feet in a fine terrace, which evidently represents the level of another lake of small area which drained by Oxdale Slack, a magnificent gorge gashing completely through a bold spur composed of hard and massive grit, into Lake Harwood Dale.

The next marked halt of the ice-front was at Cloughton Moor Cottage, where a new overflow (Fig. 10) was formed. Here the ice must have stood steadily against the hillside until the channel was established, depositing a gravelly moraine. A number of parallel scarps on the hillside near Staintondale village show the movements of the ice-margin at this period, and indicate that Lake Staintondale was again isolated. A small further retreat with slight oscillations produced the reticulated channel of Moor Lodge (Fig. 10), and subsequently the notch east of Craven Hill (Plate XII.). These drained by way of a new gorge, Stonedale, into Oxdale. A further retreat caused the cutting of the sharp valley which has isolated the hill known as Cober, and the next recession formed the splendid streamless ravine of Newlands Dale (Fig. 10), through which the Scarborough and Whitby Railway now runs. The drainage of all this area fell into the gradually expanding Harwood Dale Lake.

Lake Hackness.—In pre-glacial times a large stream, formed by the confluent becks of the great system of valleys converging on Hackness, flowed through the Sea-Cut valley to the sea at Scalby. The advance of the ice impounded this drainage, which formed Lake Hackness, with arms stretching far up into the moorland gorges north and west of Hackness (Plate XIV.). The extreme edge of the ice is marked on Seamer Moor with much precision, by a line of morainic mounds on Hagworm Hill and Riggs Head with erratic pebbles, but no foreign boulder has been found west of this line. The waters of the lake rose to 400 or 425 feet O.D., when a gap in the Corallian escarpment afforded an overflow down the dip-slope into Lake Pickering. By this time the overflow from Harwood Dale Lake would be established, and the great stream of water rapidly cut a cañon with very steep contours, Forge Valley. The ice-lobe appears o o o o o Approximate position of ice-margin at stage of retreat when a lake began to form in Staintondale.

-o-o-o-o- Line of withdrawal opening Broadlands valley.

+ + + + + Rudda Road and Cowgate Slack Stage.

• • • • • • Line of withdrawal corresponding with the cutting of Hardhurst Slack.

. . . . Stage of *re-advance* and deepening of Cowgate Slack.

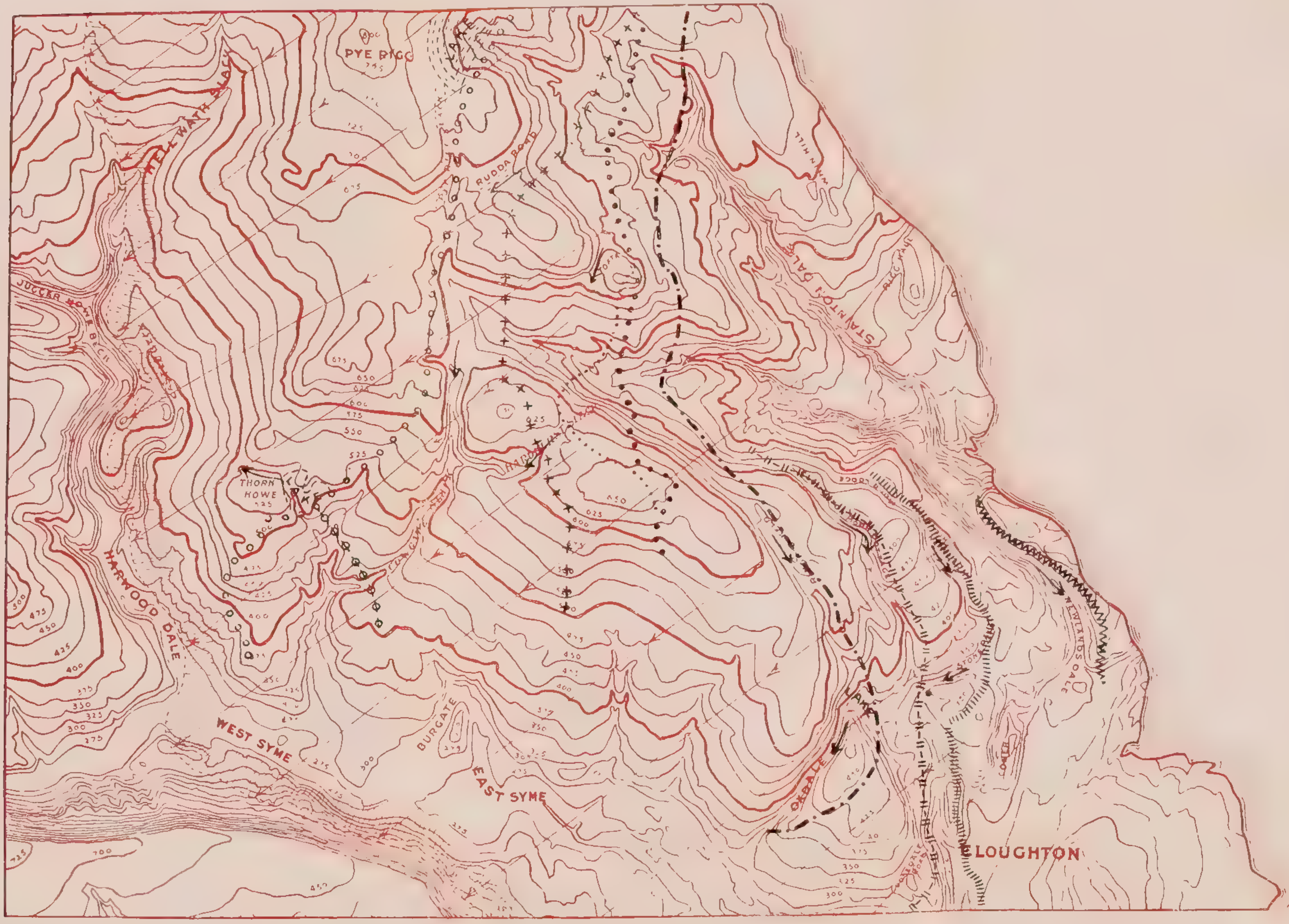
—·—·— Ice-margin at the stage when Lake Staintondale became confluent with Hayburn Lake (Ringing Keld Oxdale Stage).

-II-II-II- Cloughton Moor Cottage—Goosedale Road Stage.

IIIIIIIIIII Moor Lodge—Craven Hill- Stonedale Stage.

WWWWW Newlands Dale (Hayburn Wyke) Stage.

Several minor phases of retreat are omitted.



SCALE 0 ½ 1 2 MILES

CONTOURED MAP OF THE COUNTRY BETWEEN HELLWATH AND CLOUGHTON.

(The shaded band on the west from Hellwath Slack to West Syme indicates the approximate margin of the ice at, or near, its maximum extension.)

to have been thrust far up the Sea-Cut, as great mounds of gravel at Thorn Park are probably of direct glacial origin. That this was the extreme advance of the ice-front seems clear, for a further movement westward would have obstructed the entrance to Forge Valley, and the drainage would have overflowed at the next notch into Kimlin Slack, which then would have usurped the functions of Forge Valley.

The cutting of Forge Valley, during the maintenance of the ice-barrier, must have been continued to a depth not far short of 135 feet O.D., as the present watershed of the drift-obstructed valley of the Sea-Cut reaches only that altitude. Otherwise the Derwent would have reverted to its old channel.

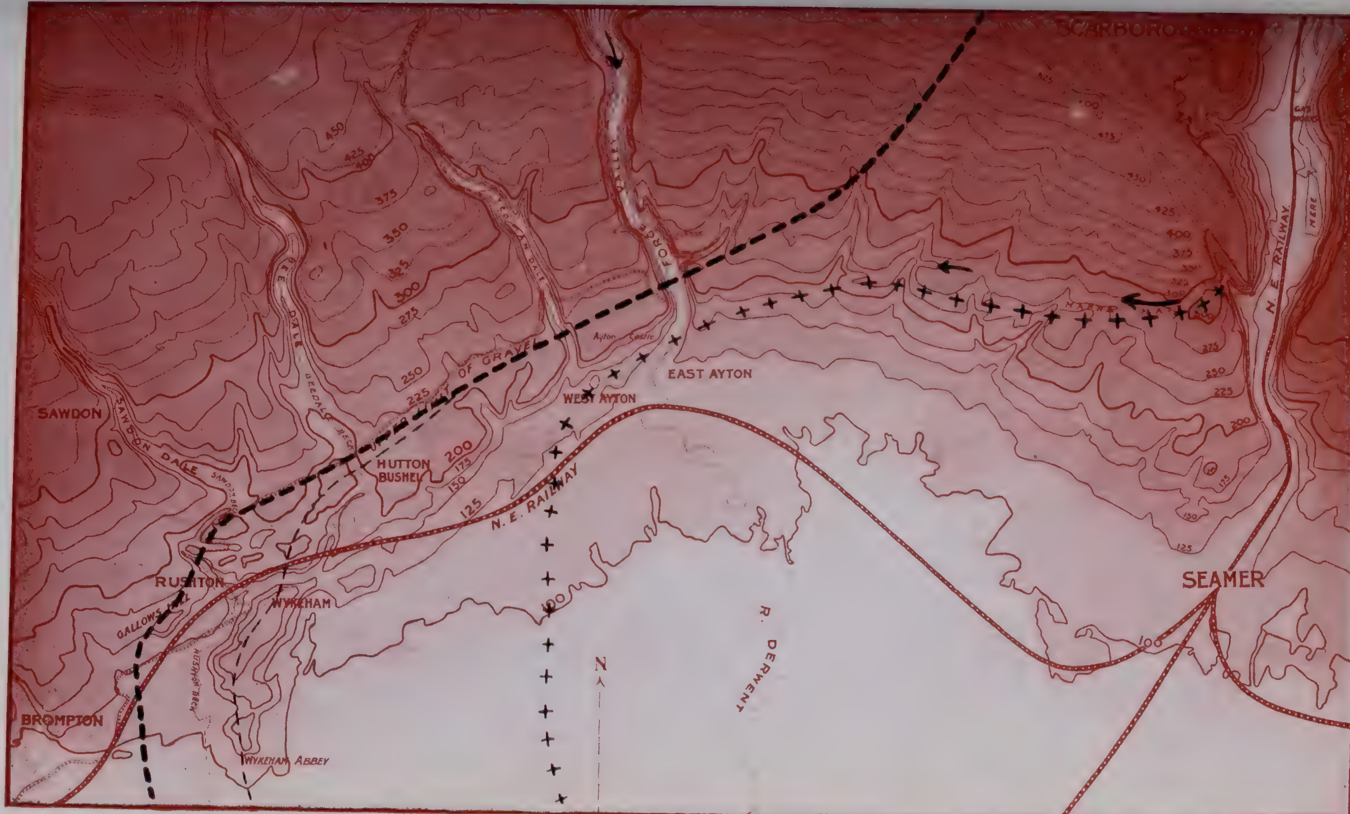
Lake Scarborough.—The indented outline of the Oolitic escarpment west and south of Scarborough shows that a lake, or a series of lakelets, must have been held up by the advancing ice. Through one of the valleys—the valley through which the railway passes from Seamer to Scarborough—a great overflow was cut (Plate XIV.). This channel is now encumbered with peaty matter, but borings prove the existence of a gorge-like glacial valley filled up with boulder-clay. It is probable that slight fluctuations of the ice-margin caused a reversal of drainage along the face of the escarpment, and the numerous lake overflows in the neighbourhood confirm this view, some of them draining northwards to Forge Valley, whilst others drain towards the Seamer Channel.

(4) Lake Pickering.

It is clear that the ice-sheet extended completely over the watershed from Scarborough to Filey, impounding the drainage of the great Vale of Pickering. This was the lowest lake of the series and for a long period received the whole of the drainage of the Cleveland area except, perhaps, its western margin, though even this is doubtful.

The Vale of Pickering is a long, faulted trough of Kimeridge Clay, lying between the dip-slope of the Corallian Beds on the north, and the escarpment of the Chalk Wolds on the south. Eastwards it opens into Filey Bay, from which it is separated by a ridge of drift deposits, which attains a minimum height of 130 feet. The floor of the valley is occupied by alluvium consisting partly of fine laminated clay and partly of sand with a little gravel. On the west the boundary is a faulted tract of Jurassic rocks in which are two gaps, one broad and flat, having a summit altitude at Coxwold of 225 feet, the other the narrow, deep gorge of the River Derwent. At the present time nearly the whole of the drainage of the country south of the Esk passes into this basin, and is diverted against the slope of the rocks and the grain of the country through Kirkham Gorge into the Vale of York (Plate XIV.). The explanation of this anomalous course is as follows :—For a long time the entrance to the Vale of Pickering was blocked by the ice-sheet which left the present moraine at Hunmanby. A lake was formed which overflowed at the lowest point of the watershed, which was on the line of a little valley running past Malton. The Coxwold valley may have been rather higher, and, in any case, at this time it was blocked by the Vale of York glacier. Kirkham Gorge having been cut down below the level of the Filey moraine before the retreat of the ice-sheet, the drainage of Lake Pickering continued to follow the same channel, and now has cut down the gorge to below 50 feet O.D.

A range of gravel mounds extending along Seamer Moor appears to mark the extreme limit of the advance of the ice-lobe. Beyond this moraine the country is free from drift. Beyond this ridge the steep slopes of the moorland towards the south are deeply trenched by dry gullies (Plate XIII.), which appear to have been produced by water flowing from the ice-front. At Seamer there is an immense spread of gravel, probably connected with two great gorges, Deepdale and the railway valley. Deepdale appears to have carried off the drainage of a small lakelet about Wheatcroft, on the road between Scarborough and Filey. Between the railway and Forge Valley several small valleys occur, which, after running for some distance from east to west, swing southward. Associated with them there are many intermittent gravel mounds. To the north of East Ayton, at the mouth of Forge Valley, and thence onward to Gallows Hill, between Wykeham and Brompton, extends a great gravel bench which has a breadth of from a quarter to half



RELIEF MAP OF THE COUNTRY FROM WYKEHAM TO SEAMER, SHOWING THE APPROXIMATE FORM OF THE GRAVEL BENCH AND THE DEVIATION CHANNELS.

SCALE: 1¼ inches to 1 mile.

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

a mile. Its upper edge, where it rests upon the slope of the hills, falls from 245 feet on the south of Forge Valley to a little over 200 feet at Wykeham. Four deep valleys come down to this gravel bench, and each of them on reaching it undergoes a sharp westerly deflection. Moreover, across the flat top of the gravel terrace, a series of deep channels has been left, forming an almost complete series of links connecting each valley with its neighbour on the west. At the western end, by Wykeham and Rushton, the terrace is extremely uneven, and it comes to an abrupt and singular termination in a great horn, running for nearly a mile out into the valley, forming a bold ridge on which Wykeham Abbey is situated. Shell fragments are common in these gravels and they contain many erratics, including Cheviot andesites, jasper pebbles, Magnesian Limestone, gneiss, and granite.

The persistent westerly "aberration" of the debouchure of the valleys points to the operation of some constraining agent which is no longer present; and when the deserted high-level channels which linked these valleys together are reviewed, and found to indicate a similar persistent tendency, the constraining agent seems to be clearly indicated—ice in the form of a glacier-lobe would produce this effect. Upon this hypothesis, the edge of the great ice-sheet passed farther inland, where it encountered the feeble opposition of the range of heights to the south of Scarborough, than it could to the northward, where it was opposed by a bolder country, and so was enabled to thrust its way up the Vale of Pickering to, and a little beyond, Wykeham. The phase of maximum extension is, on this view, indicated approximately by the gravel-patch on Gallows Hill. After a very brief sojourn at this extreme extension, a protracted halt took place about Wykeham, and the great gravel-mass there appears to be the terminal moraine of this ice-lobe.

Under the conditions now set up, we may suppose the Forge Valley overflow to have come into operation, and a vast quantity of water from the extensive area of land and ice to have come down the incipient channel. This stream would bring over a few erratics, along with immense quantities of gravel and stones obtained from the denudation of the gorge; and these materials, mingled with lateral moraine, would be washed into the space between the margin of the ice-lobe and the hills to form a species of deformed delta. The stream would thus turn towards the only point of escape, Lake Pickering, and would spread its gravels to form a bench along the ice falling from east to west. Each valley descending the ice-free slopes west of Forge Valley would behave in the same way as the main stream and turn westwards along the gravel bench. As the lobe receded, successive avenues of escape for the streams would be afforded along the ice-front, and thus every step of the retreat would leave a segment of the main channel high and dry upon the top of the gravel terrace.

As the ice slowly retreated, its lateral dwindling would allow the river to flow between the elevated terrace and the ice, which would result in some scarping of the gravel bank, and a partial redistribution of its materials, until the retreat left the mouth of Forge Valley open and the waters of the Derwent debouched directly into Lake Pickering.

After the glacier-lakes were formed by the invasion of the ice-sheets, Lake Pickering would receive practically all the drainage of the Cleveland area, from the Ingleby Greenhow Lake by Bilsdale, from all the North Cleveland Lakes and Lake Eskdale by Newton Dale, and from the East Coast Lakes by Forge Valley. Lake Pickering in its turn discharged its waters by Kirkham overflow into Lake Humber, a great glacier-lake held up in the great central valley of Yorkshire by an ice-dam at each of its exits. What were the southern limits of this lake cannot yet be certainly defined. That the mouth of the Humber and the Wash were obstructed by the North Sea ice seems pretty certain, and the distribution of the chalky boulder clay indicates a great barrier of ice far westwards along the Trent valley. This proposition is supported by the existence of fine laminated muds of identical character with those of Eskdale in the Vale of York, and far southwards in the Midlands, but no signs of deltas or beaches have been noted. The line of the overflow of this great lake southwards has not yet been identified, but when the glacial evidence of South Yorkshire, Derbyshire, and the mid-English plain is carefully worked out, we may hope that the course of the waters to the ocean, probably by way of the Straits of Dover, will be revealed, and the full story of the English glacier-lakes be clearly unfolded.

For the full evidence on which the foregoing conclusions are based the Editors beg to refer the reader to Mr. Kendall's paper in the Quarterly Journal of the Geological Society of London, Vol. LVIII., pp. 472—571, of which the above paper is a rearranged condensation. They desire gratefully to acknowledge the generous kindness of the Council of the Geological Society of London in lending the blocks by which the present paper is illustrated.

SUPPLEMENTARY OBSERVATIONS ON THE GLACIER LAKES OF CLEVELAND.

BY PERCY F. KENDALL, F.G.S.

The paper in the Quarterly Journal of the Geological Society (Vol. LVIII.), of which the foregoing is an abridgment was extended at great length by the obligation which I conceived to be cast upon me of not only dealing with a complicated train of phenomena, but also of laying before geologists evidence of factors in the glaciation of this country which had not been dealt with by any previous writer. I found, however, that even the generous amount of space allowed me for the exposition of the subject was insufficient, and many points of great interest were passed over without as full a treatment as I think their importance demanded. Questions, moreover, arose in the discussion on the paper, and during the excursion of the Yorkshire Geological Society to Cleveland, which I desire to clear up.

(1) *Overflow Valleys with Two-fold Drainage.*—I mentioned two overflow channels at the north-eastern angle of the Silpho Moors, each of which seems to indicate alternate flow of lake waters from east to west and from west to east through the same channel, an alternation which I had already shown (Q.J.G.S., Vol. LVIII., p. 554, 3rd par.) to be *a priori* probable, as there were possible outlets at both ends of the escarpment which might by slight fluctuations of the ice-front be opened alternately.

On the occasion of the excursion to Whitby and Scarborough I explained my reasons for this interpretation, and I take this opportunity of placing them on record.

An outstanding spur is cut through by successive parallel channels, the small outer one being at a considerably greater elevation than the inner one, which contains Throxenby Mere. The outer channel shows most clearly the characters I wish to describe, and I will therefore confine my attention to it. A section along the floor of the valley shows that it is crossed by a transverse watershed. This was the significant feature upon which I based my conclusion, and for its explanation it is necessary to recall the conditions attending the cutting of a lake channel parallel to the ice-front. Let us imagine a lake held up by an ice-barrier, and draining across a col into another lake at a lower

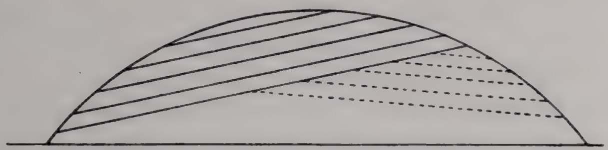


Fig. 11.

level. Suppose the section across the spur at the col to be semicircular (Fig. II.). The watershed will at first be on the summit of the semicircle, but as the overflowing stream wears a channel for itself, the watershed will gradually advance towards the higher lake. Now reverse the flow, and the watershed will retreat towards the centre, and perhaps past it, as indicated by the broken lines in the figure. This is the position of the watershed in the little channel referred to.

(2) *Relative Duration of the Stage of Retreat of the Ice-sheet.*—Another subject upon which I think it desirable to add some observations is the evidence afforded through the district of the relative duration of the stages of retreat of the ice and of a general but brief readvance.

The relative rate of retreat and the duration of the halts may be judged by the magnitude of the moraines, when present, and of the overflow channels. Moraines are very imperfectly developed in the area, but the small patch of gravel on Gallows Hill, in advance of the Wykeham moraine (Q.J.G.S., Vol. LVIII., p. 559), seems to indicate that the lobe of ice which entered the Vale of Pickering stood for a short time at, or beyond, that point, then retreated to make a long halt at Wykeham and throw down the great moraine mass upon which the Abbey stands.

The evidence of the overflow channels is much clearer and more decisive.

The maximum extension of the ice is in a large proportion of cases indicated by a range of very small and shallow channels, indicating a mere "touch and go" advance and retreat; behind this there is generally to be found a large, well-developed channel, like that crossing Murk Mire Moor, above Goathland, telling of a prolonged halt. The next stage is a rather rapid retreat to a position of much greater stability when all the largest channels of the district were cut. This is well illustrated by the Moss Swang channel, near Goathland. Intimately connected with this stage is a slight, general readvance of the ice, shutting the half-formed channels and cutting others further forward, or deepening some previously-formed channel. The evidence upon which I conclude that there has been such a forward movement of the ice-front is well displayed in Fig. 10 (p. 33). Here a section of the long spur sloping from W. to E. down to Hayburn Wyke Station shows six successive channels produced by the drainage of a lake on the northern side during the shrinkage of the ice-front from W. to E. for a distance of less than a mile and a half. It will be observed that the intake of the most westerly of these channels, Cowgate Slack, is at an altitude of 580 above sea-level, while the next channel eastwards, Hardhurst Slack, opens at 607 feet. It is manifest that, as they were both produced by the overflow of the same lake, the easterly one must have been cut before the more westerly, and this implies that, after the ice had retreated to the east of Hardhurst Slack, it readvanced and closed the channel long enough for Cowgate Slack to be cut below the level of the Hardhurst intake. Thus, when the ice-margin again retreated, Cowgate Slack remained the functional drainage channel. Other cases of a similar character occur, which seem to me to point to a general forward movement of the ice-sheet round the Cleveland area. The deserted oxbow at Castle Hill above the Moss Swang Valley, Goathland (Plate VI.), and those at Hardale Slack, Roxby (Plate III.), Biller Howe Dale, Evan Howe Slack, and Castle Rigg (Plate X.), may not all belong to the same movement, but I think that, while the Hardale Slack and Biller Howe Slack examples, which are clearly correlated, belong to an earlier and very slight readvance, those of Castle Hill, Evan Howe Slack, Castle Rigg, Cowgate Slack, and the

Throxenby Mere channels, mark a synchronous, more extensive, and more prolonged forward movement at a later period.

I have observed in other parts of the country similar evidence of fluctuations of the ice-margin, notably in the country west of Ripon, in the Cheviots, the Vale of Eden, and the northern face of the Lammermuirs.

(3) *Comparison of the Levels reached by the Ice-margin round the Cleveland Area.*—The levels attained by the ice-margin round the Cleveland area, as indicated by the lake phenomena and distribution of drift-deposits, present some apparent anomalies, which, however, admit of a very simple explanation. The large general map which accompanies this paper (Plate XIV.) shows by a series of arrows the direction in which I suppose the ice to have been moving at the stage of maximum extension of the ice, and it shows also the approximate position of the margin. It will be observed that there is a general decline of the margin from North to South which might not unreasonably be ascribed to the dwindling of the ice-sheet as it extended further and further from its source. But when the levels attained along the northern face are compared it is seen that the margin rises in a westerly direction and reaches a much higher altitude along the great escarpment above Carlton and Ingleby Greenhow than on the hills above Moorsholm and Iburndale, though further from the source of the ice. Why is this? Well, it must be observed that we are dealing with the *edge* of the ice, and the height to which it will rise is dependent as much upon the character of the obstacles which it has had to surmount as upon the thickness of the stream or sheet which it bounds.

It will be noticed that the ice which bore in upon the great Cleveland escarpment (the real Cleve-land, or land of cliffs) traversed a great plain with scarcely a hillock to obstruct its passage, whereas that which was driven in upon the hill country further east, though descending from the same great flood, was hampered and the force of its onset weakened by its struggle to surmount the broken ground confronting its march.

The same principle is most instructively illustrated by the drift phenomena of the country between the cliffs at Peak and the terminal moraine on the brink of the great gorge of Jugger

Howe Beck, near Castle Head Farm (see Fig. 9 and Plates XII. and XIV.). The moraine, which in all probability marks the furthest extension of the ice, attains an altitude of just over 450 feet above sea-level, yet the ice which produced it not only surmounted the lofty cliffs more than 600 feet high at Peak, but overrode hills of 800 feet altitude in the intervening ground.

Another rather different application of the same principle explains why no marginal channels are visible on the hills south of Slapewath, two miles E. of Guisborough (see Fig. 12); the outstanding mass of Airy Hill (to the west of Boos Beck, in

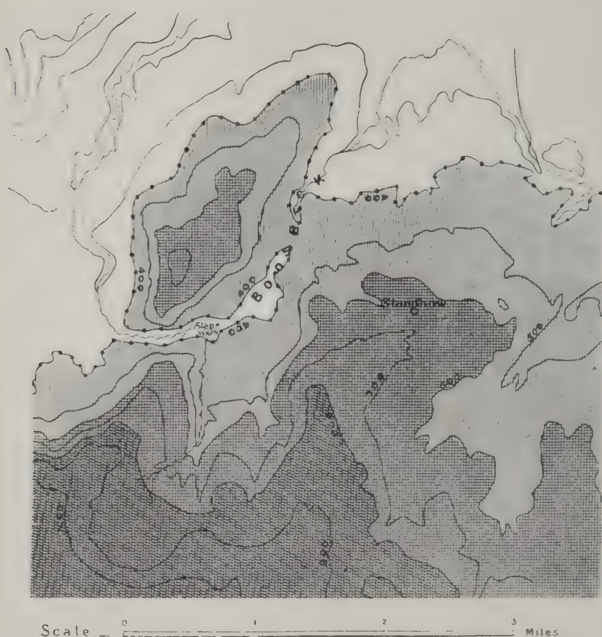


Fig. 12.

MAP OF THE BOOS BECK VALLEY, SHOWING THE DEVIATION OF THE STREAM AT SLAPEWATH.

Fig. 12) acted as an effective fender to keep the ice away from the main slope of the Cleveland Hills, so that a sinuous lake would lie along their front, probably extending further to the westward than I have shown in my large map. This explanation is of wide application, and not only have I found a very close counterpart in the Lammermuirs, near Borthwick Castle, but I was enabled to explain an unseen case in the Dublin Mountains, described to me by my friend Mr. H. J. Seymour, B.A., of the Irish Geological Survey, and to predict the existence and position of an outlying hill which acted as a fender.*

* See Geol. Surv. Mem. on the Geology of the Country round Dublin, p. 119.

NOTES ON BOULDER MARKINGS ON MR. KENDALL'S MAP OF THE GLACIER LAKES IN THE CLEVELAND HILLS.

BY JAMES H. HOWARTH, F.G.S., HON. SECRETARY OF THE YORKSHIRE BOULDER COMMITTEE.

Mr. Kendall has accorded me the privilege of marking upon his glacial map of the Cleveland area the results of the researches of the Yorkshire Boulder Committee.

As Honorary Secretary I have in my possession the records of the labours all over the county of the members of that Committee and of many other persons who have furnished records and supplied returns. These represent a vast amount of patient work carried on continuously for the last 17 years. During that period many thousands of records have been made, but the facts they represent have only of very recent years begun to fall into line and to establish certain definite principles illustrating the causes of the distribution of glacial erratics in Yorkshire.

The Yorkshire Boulder Committee has always been extremely chary of drawing definite conclusions, and has again and again resisted temptations to generalise, but has chosen rather to wait patiently and to go on accumulating facts from year to year. Out of the mass of information accumulated certain conclusions may now, however, very fairly be drawn ; conclusions which have for some years past been gradually forcing themselves upon the minds of the Committee, and which each succeeding year's work seems to further illustrate and support.

Mr. Kendall has very kindly suggested that I should accompany the marking of his map with some notes. This I propose to do entirely from the point of view of the Boulder Committee as formed from its records.

Of course it must be understood that I cannot pledge the Committee or its individual members to the way in which I may express their general conclusions ; but I have an especial pleasure in adopting Mr. Kendall's suggestion because it will be seen at once that the Boulder Committee's work falls into line and harmonises with Mr. Kendall's conclusions (formed from much evidence besides boulders) in a very interesting and satisfactory way. Special attention is directed to sections VI., VII., and IX. of Mr. Kendall's paper in the *Quarterly Journal of the Geological Society*, Vol. LVIII.

Although, as I have said, many thousands of records have been made, the map is now marked only with such rocks as are (1) entirely foreign to the county, and (2) of types which are capable of definite identification.

Mr. Kendall has well described the directions of source of boulders as "Western," "Northern," and "Eastern," and these terms I accordingly adopt.

The Western Group.

(Cumberland and Westmoreland Rocks marked "C" and "W" respectively on the Map.)

Rocks from this the "Western" area are widely distributed in Yorkshire. They range all along the east coast down into Lincolnshire, and inland from the coast to elevations of over 800 feet O.D., and to 30 to 120 feet below the surface in borings at North Ormesby, near Tees-mouth.

They occur spread over the central plain of the Vale of York, from the Tees to Doncaster, abutting against the Hambleton Hills on the east, and reaching to five miles west of Ripon on the west. They occur also plentifully in the valley of the Yorkshire Calder from Todmorden to below Wakefield.

These rocks reached Yorkshire by two principal and widely divergent routes.

Those of the east coast and the Vale of York are traceable up the Tees valley to just below Middleton-in-Teesdale, and over the pass of Stainmoor (1,800 feet) to Brough in Westmoreland.

Those distributed along the east coast appear to have passed out at Tees-mouth, carried by a glacier having free access to the North Sea. Boulders have been dredged up many miles from the coast.

Later, this free outlet was interrupted by ice advancing across the North Sea in a south-westerly direction, and sweeping down the coast of South Scotland, Northumberland, Durham, and Yorkshire in such force as to dam back the local glaciers, and to distribute their terminal moraines along the east coast, mixing them with the Scandinavian rocks which the invading ice carried.

To the foreign ice-sheet the east coast cliffs acted as a buffer, but its south-westerly trend enabled the coast line to deflect it southwards, and the British ice which reached the coast was dragged along with it. Where the coast line was lower it invaded the land for shorter or longer distances as the surface elevation (relative to the pressure of the ice-mass) controlled it, so that in north-east Cleveland it either forced its mass or some of its contents many miles inland, and again at Scarborough and in Holderness.

Indentations in the coast-line, protected by cliffs with their curves turned north-eastwards, acted as catchment basins for erratics, so that they are more plentiful in such places as Robin Hood's Bay, Scarborough, Speeton, Gristhorpe, the north side of Flamborough, etc. In such localities they occur in thousands. In many places the ice topped the cliffs, depositing boulder clays, while in others it failed to do so.

The blocking of the mouth of the Tees compelled the Stainmoor and Teesdale glacier to leave its old course and to turn down the Vale of York, carrying with it its burden of Lake Country rocks. These are traceable all down the Vale of York as far as Escrick. They are also found at Doncaster, but it is not certain at present whether the Tees ice reached further south down the Vale of York than the two moraines at and near York.

A line drawn from about Workington, on the coast of Cumberland, by the southern watershed of Thirlmere, and round to the west side of Wastdale Crag in Westmoreland, would appear to mark the boundary line or "boulder-shed" by which the Western group of rocks reached Yorkshire. Rocks north of that line travelled to Yorkshire and the Cleveland area by the Stainmoor and Tees route. There are, however, a few exceptions to this general rule. Eskdale granite, for example, has been recorded north of this line, whereas its general distribution is southward of its outcrop. Similarly Shap granite, the outcrop of which is north of this suggested line, is distributed far to the south-west; but these dispersals were probably in the earlier stages when the local glaciers had free outlets.

The rocks from Cumberland, marked "C" on the map, include Armboth Dyke, Carrock Fell gabbro, and Borrowdale andesite. Those from Westmoreland, marked "W," are principally Shap granite, but include the distinctive Brockram from the same county.

It should be remembered that these rocks are everywhere accompanied by others picked up all along the route, and of course greatly exceeding them in numbers.

For instance, the "Western" group is accompanied by great numbers of boulders of Carboniferous limestones, sandstones and cherts, Whin Sill, etc., and the same rule applies to the "Northern" group, to be mentioned presently, which are accompanied by greywacke sandstones and conglomerates, and magnesian limestone of the Roker type, etc.

These, however, are not marked, in order not to load the map, and so perhaps confuse the three distant directions of source.

The Northern Group.

Rocks from Durham County, the Cheviot area of Northumberland, and Scotland are present in the Yorkshire drift, including the Cleveland area.

These include andesites and porphyrites from the Cheviots, probably both from the English and Scotch side, but the former predominating; the characteristic "Haggis" rock from the northern edge of the southern uplands of Scotland; and red jasper, sanidine trachyte, dolerites, and basalts from the southern uplands of Scotland. These are all marked "S" on the map.

There are also records of certain Highland schists from as far north as the Ochill Hills in Perthshire, identified by Messrs. Peach and Cunningham-Craig of the Geological Survey of Scotland. These are marked "H."

These rocks seem to have been first carried out to sea in south-east Scotland, eastern Northumberland, and Durham, and to have been deflected southwards by the Scandinavian ice-sheet, as the Tees glacier and its contents were.

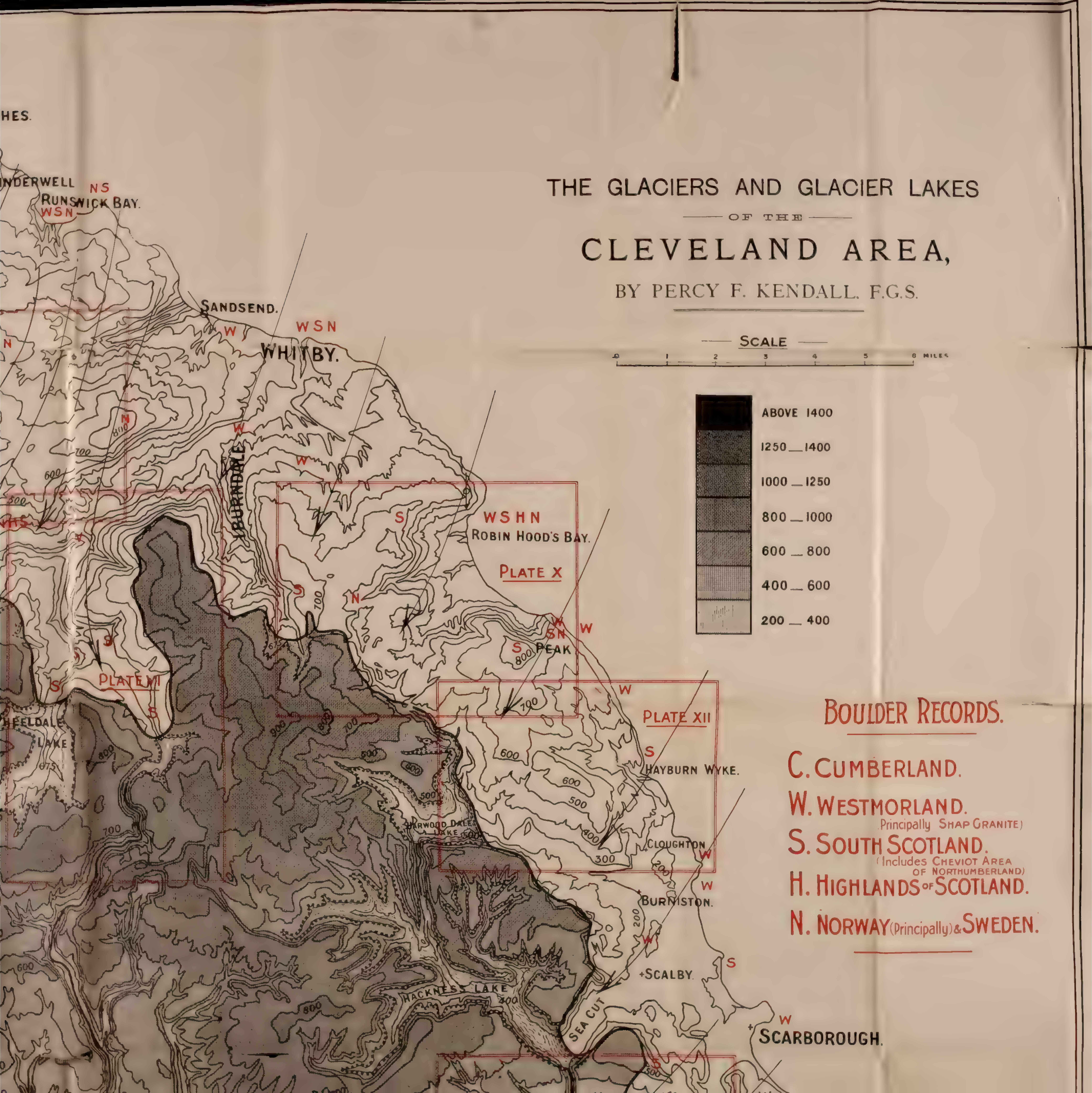
Porphyrites of the Cheviot type are the most abundant, and are everywhere along the Yorkshire coast, and further south into Cambridgeshire. They are found also at many inland localities, including Barton-on-Humber, about Beverley, at Seamer, at Wykeham, in the Vale of Pickering, in Yedmandale, at Goathland, at Carlton Bank, Bold Venture, and Scarth Nick. They range from sea-level up to 950 feet O.D.

The fact that they are also found among the highest drift deposits along the northern face of the Cleveland Hills and on the eastern side of the Vale of York about Thirsk, seems to indicate that the Northumberland and Durham local glaciers were, like the Tees glacier, prevented from discharging seawards. They were thus compelled to turn southwards across the Tees, and were forced up the northern slope of the Cleveland Hills by the Scandinavian ice on the one hand, and the Tees glacier (which similarly had to turn southwards down the Vale of York) on the other.

The Eastern Group.

Boulders of Scandinavian origin and marked "N" on the map are found in great numbers on the shore on the coast of Yorkshire, in the clays and gravels forming the coast-line, on the top of the coast cliffs at the Peak and Speeton, and at many places inland, both in drift material and on the surface. They range from Saltburn all along the coast to Redcliff and Ferriby on the Humber, and in vertical distribution from the sea-shore to 810 feet above sea-level. In a gravel pit at Burstwick in Holderness they were found 16 feet below the surface.

MIDDLESBOROUGH
STOCKTON
ESTON
ESTON MOOR
SALTBURN
GUISBOROUGH
STAITHES.
HINDERWELL
RUNSWICK BAY.
MOORSHOLM
FIG 12
PLATE V
PLATE I
PLATE III
PLATE VII
KILDALE LAKE
MORAINE
LAKE ESKDALE
STOKESLEY
INGLEBY GREENHOW
CARLTON BANK
CARLTON
SCARTH NICK
SCUGDALE LAKE
OSMOTHERLY
BILSDALE
RALPH CROSS
GLAISDALE
WHEELDALE LAKE
ROSEDALE
FARNDALE


THE GLACIERS AND GLACIER LAKES
OF THE
CLEVELAND AREA,
BY PERCY F. KENDALL, F.G.S.
SCALE
0 1 2 3 4 5 6 MILES
ABOVE 1400
1250 _ 1400
1000 _ 1250
800 _ 1000
600 _ 800
400 _ 600
200 _ 400
BOULDER RECORDS.
C. CUMBERLAND.
W. WESTMORLAND. (Principally SHAP GRANITE)
S. SOUTH SCOTLAND. (Includes CHEVIOT AREA OF NORTHUMBERLAND)
H. HIGHLANDS OF SCOTLAND.
N. NORWAY (Principally) & SWEDEN.
HES.
NDERWELL
RUNSWICK BAY.
SANDSEND.
WHITBY.
BURNDALE
ROBIN HOOD'S BAY.
PLATE X
PEAK
PLATE XII
PLATE VI
HAYBURN WYKE.
CLOUGHTON
BURNISTON.
SCALBY.
SEA CUT
HACKNESS LAKE
HARWOOD DALE LAKE
SCARBOROUGH.

Proceedings, Yorkshire Geological and Polytechnic Society, Vol. XV., Plate XIV   Reproduced by permission of the Council of the Geological Society, from Q.J.G.S., Vol. LVIII, 1902, Pla

of the Council of the Geological Society, from Q.J.G.S., Vol. LVIII, 1902, Plate XXVIII.

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In the area comprised in this map (Plate XIV.) they are recorded on the beach at Saltburn, Whitby, Kettleness, Robin Hood's Bay, Gristhorpe, and Filey: at Ayton, Seamer, Hutton Bushell in the Vale of Pickering, and Yedmandale.

They are also found at Kirk Moorgate, near Whitby, at 550 feet O.D. At the Peak at 600, at Danby at 625, at Stump Howe at 650, on Eastington High Moor at 700, and at West Rigg at 810.

The following rocks have been definitely identified and from their distinctive characters continue to throw much light upon the distribution of non-British erratics in Yorkshire :—

Rhomb Porphyry
Augite Syenite (Laurvikite)
Zircon-Syenite
Elaeolite-Syenite
} from Southern Norway.

Sandstone or Grit (Sparagmit-Conglomerat) from north of Christiania.

Post Archaean Granite from Angermanland in Sweden or Aland on the Gulf of Bothnia.

Halleflinta from Sweden.

Syenitic-dyke-rock from Longen Valley or north of Christiania.

All the above, with the exception of the Archaean Granite and Halleflinta, are recorded within the area covered by the map.

NOTES ON THE GLACIAL PHENOMENA OF PART OF WHARFEDALE, NEAR GRASSINGTON, FROM MY MS. WRITTEN IN 1878.

BY J. R. DAKYNS, M.A. (FORMERLY OF H.M. GEOLOGICAL SURVEY).

(*Read February 27th,* 1902.)

With the exception of blocks of Silurian rock, which are found between Chapel House and Burnsall, the drift in the basins of the rivers Wharfe and Nidd, among the Carboniferous rocks, contains only Carboniferous boulders which may have come from the rocks cropping out of the surface in those basins. There are no foreigners. We know that the drift material has travelled southward and eastward, because boulders of Carboniferous limestone are found to the south and east of any outcrop of that formation; thus boulders of limestone have been carried southward across the Aire to the higher part of the Worth Valley, and such have also travelled eastward down the Aire valley towards Leeds.

There are very few Glacial striæ to be seen near Grassington, because there are not many hard compact rocks fitted for retaining striæ. Limestone is hard and compact enough, but it disappears so rapidly at the surface under the action of rain-water, and becomes so fretted into fantastic shapes, that it does not long retain superficial markings, except when protected from the weather by a covering of clay. One very good instance of this sort occurs between Grassington and Kettlewell, at a spot on the east side of the valley, where under boulder clay I found limestone beautifully grooved. The grooves trended along the hillside bounding the valley of the Wharfe. The only other scratches I got were on Millstone Grit on the southern part of Hebden Moor, where I found scratches trending N.W. and S.E., and close by some doubtful ones pointing E.N.E.

The valley of the Wharfe is crossed at Grasswood, a mile above Grassington, by a barrier of limestone, through which the river runs in a narrow channel; above the barrier stratified sand and gravel is found. There is every appearance of this rock barrier being the lower lip of a rock basin filled with drift and alluvium. It is difficult to say how much of the sand and gravel is of the glacial period, and how much is more modern river gravel. The river gravels probably run back to glacial times.

A similar barrier of coarse grit stone crosses the valley at the elbow in the stream below Dribley. The hills on either side of the river, formed by this rock, are called Herds Hill and Heugh. Herds Hill has a distinctly glaciated look, as seen from a distance; but I could not find any scratches, for the retention of which the rock is, in fact, too coarse. I found, however, something like grooves running N.N.E. and S.S.W. This hill, with the Heugh on the opposite side of the river, forms a prominent bank of grit stretching across the valley, which it would dam up but for the narrow passage which the river has cut for itself. The drift is piled up against the high side of this dam. Gravel mounds enclose the Heugh on the north-west. These mounds gave no section; but externally they look like Eskers, as they are moundy and enclose hollows. They attain an altitude of 600 feet above sea level.

In constructing the puddle trench of the Barden reservoir for the Bradford Corporation waterworks a total thickness of 65 feet of drift was met with; the section, as kindly communicated to me by the residing engineer, was as follows:—

Yellow clay, 10 feet.
Blue clay, sandy and stony } 13 feet.
Sand and gravel }
Blue clay, 42 feet thick, hard and watertight; containing limestone boulders and great blocks of grit.

The yellow clay at the surface is doubtless merely the weathered part of the blue clay.

As both grit and limestone occur in place in large masses in the district, it is of no special importance finding boulders of one rock lying on the other; but I may mention that the limestone ridge above Fancarl House, though free from drift and generally bare, is strewn with boulders and blocks of coarse Millstone Grit. I found, too, a block of limestone on the Kinder Scout Grit Escarpment at the southern end of Crookrise Crags on Embsay Moor.

The curious round hills forming the Millstone Grit Escarpment south of Barden, between the river Wharfe and the Pateley Bridge road, have limestone boulders on them.

At Gill Bank, near Storriths, flaggy Grit, dipping at 60° to the S.E., looks as if the ends of the beds had been turned over southward and broken. Ice moving from the north might have done this.

The only other case of terminal curvature that I am acquainted with in this neighbourhood presents some difficulty. It occurs on the northern slope of hills forming the south part of Barden Moor. In a quarry near Hutchin Gill Gate the beds, which consist of flagstone, are dipping downhill, i.e., to the north at 25°; and the top layers are turned over, as if by a force acting downhill, i.e., from south to north. The slope of the ground does not seem to me sufficiently great for this bending over to be due to the "weight of the hill," as it is called. On the other hand, it is quite certain that the great mass of ice moved southward. If this bending over was caused by ice it must have been by quite local ice.

As regards the drift material, it is of two sorts, well-rounded and bedded gravel and sand, and ordinary boulder drift. This latter bed is the most frequent. It cannot always be called boulder *clay*, and in the higher parts of the dale but seldom so, for it often consists of a mass of both rounded and angular stones, of all shapes and sizes, with very little clayey matter at all. The difference, however, between it and boulder *clay* is mostly one of degree: where the drift is derived from hard, indestructible rocks, there will be a stony deposit with but little clay; where it comes from shale there will be much clay.

It is quite impossible, as a rule, to separate the boulder beds from the sand and gravel, for the boulder beds, when stony, and when the stones are well rounded, approximate to gravel; and, moreover, as the section of the Barden Reservoir shows, sand and gravel are sometimes intercalated in the midst of boulder clay. Consequently no general sequence can be made out; but near Linton Mill gravel certainly lies on the top of boulder clay, for there is a steep bank, the upper part consisting of dry gravel and the lower of wet clay, which throws out the water percolating the first; but as there is no section to be seen, it is impossible to tell whether the gravel is a scratched boulder gravel or a water-washed gravel.*

Near Park Bridge, over the Wharfe, there is above the alluvial flat a bank of gravel, which though very rough and unstratified in some parts is on the whole distinctly stratified. It contains subangular blocks of Millstone Grit about three feet in diameter. This gravel continues some way up stream.

Opposite the Lud Stream islands there is a gravel in a similar position and apparently of the same general character, but the section is not clean cut. It is surmounted by another bank of gravel (section also not good) apparently of the same character, but containing much larger subangular blocks of grit. The top of this gravel bank is 75 feet above the river, and thence there stretches a gently rising and undulating surface for about one-sixth of a mile to the foot of the hill called South Nab. This plateau may be all of gravel.

On the left bank of Posforth Beck, a little below the first bend in the stream above its junction with the Wharfe, there is a section in true glacial drift. The material consists of angular débris of grits and limestones; the blocks of the latter are well

* Note on the gravel near Linton Mills mentioned in my MS. of 1878. I have just learned from Mr. Percy Kendall that the gravel near Linton Mills, which was quite hidden by grass when I was surveying in Wharfedale, is now well exposed, and that it is, in his opinion, undoubtedly a glacial gravel.—J. R. D., March 9th, 1902.

glaciated. The deposit also contains fine stratified sand, beautifully false-bedded, round which the boulder drift seems to wrap; but the section is not quite clear. Farther down stream there is a similar angular deposit. There are plenty of rounded stones, but the characteristic is angularity.

Pickles Gill, above its junction with Tom Taylor Dike, is full of drift, consisting of angular blocks and pebbles of grit and limestone; the pebbles are mostly of limestone, and the limestones are smoothed and scratched.

It is not necessary to give any more details of sections, as it would be merely a repetition of what has been already said.

The general result is this—that the boulder beds vary from a true boulder clay to a stony mass; that this consists sometimes of a heap of angular fragments, while at others it contains a large number of pebbles; that in the latter case, on the Millstone Grit area south of Grassington, the larger portion of the pebbles are of limestone; and that the limestones are generally scratched, the grits but rarely. Evidently the reason why the greater number of pebbles are of limestone is that the limestones have come a greater distance.

Further, the true glacial boulder beds are mixed up with finely stratified sand and gravel.

Lastly, well water-worn gravels, containing large boulders and angular blocks, line the valley sides in terraces, like ordinary river terraces. This makes me think that there is no real distinction to be drawn between the older river gravels and the water-worn boulder gravels, which are generally set down to the Glacial Period as something quite *sui generis*. I believe, on the contrary, that the ordinary river gravels run back to Glacial times and gradually merge into the deposits of that age.

As I have already described the occurrence of Silurian boulders in Wharfedale, I will merely say that these boulders, which are like rocks that occur in place in Ribblesdale, are confined to the portion of the valley between Chapel House Lodge and Burnsall; that is, all that I have met with are below Chapel

House Lodge, and they do not extend quite as far as Burnsall. They are most plentiful about Linton and Threshfield. The greater number of them have long since been cleared off the ground and built into the walls as "throughs," where their remains may still be seen; but some few I found still lying about on the surface of the land; and some may be seen in the section cut through the drift by becks descending from Threshfield Moor. I could find none above the general level of the drift of the more open country, which near Threshfield reaches the height of 900 feet above sea-level. I examined the country between the site of the boulders and the outcrop of Silurian rocks in Ribblesdale; but though there are plenty of Millstone Grit boulders lying on the bare surface of the limestone, not a single Silurian boulder was to be found. It is quite clear that these Wharfedale boulders did not come over the fells from Ribblesdale. It may be thought at first sight that they came on floating ice discharged from a glacier debouching at the mouth of Ribblesdale near Settle. But there are great difficulties connected with this view, the chief of which is this: If boulders drifted eastward from Settle on floating ice when the sea level was but little higher than the present 900 feet contour line, and Wharfedale was a fjord, how did they, surmounting the rock-barrier at Netherside, travel *up* the dale or fjord towards Chapel House? For assuredly ice, or water carrying ice, was flowing down Wharfedale all the while. I believe the true explanation of the origin of the boulders to be this: At the foot of Kilnsey Crag strong springs break out from the limestone just above the level of the alluvium; also in Littondale strong springs break out at the foot of the limestone scars, the hillside below being formed of a mass of detritus, which as completely conceals the underlying rocks as does the alluvium at Kilnsey. Seeing then that strong springs break out at the foot of scars formed by limestone of great thickness, and that it is only at a short distance below the springs that we begin to find Silurian boulders in the dale, it seems likely that the springs are thrown out by Silurian rocks in place in the bottom of the valley, concealed from sight by superficial detritus, drift, and alluvium; and that our boulders were thence derived. This makes everything simple; and the thickness it allows to the limestone is quite equal to the thickness seen in Ribblesdale.

In conclusion, let me say that thus far the Glacial phenomena of Wharfedale lend no support to the theory that the whole country was over-ridden by an ice cap descending from the pole, for there is no evidence here of foreign ice; but everything is in favour of huge confluent glaciers, or ice sheets (if that term is preferred), of home-made ice.

Nidderdale, too, supports the same conclusion: there are no foreigners there at all.

Large gravel mounds of an older date than the river terraces occur both above and below Pateley Bridge. These may be Eskers. They reach a height of between 400 and 500 feet above the sea.

CHEMICAL DATA FOR THE ROCKS OF THE ENGLISH LAKE DISTRICT.

BY ALFRED HARKER, M.A., F.R.S., F.G.S.

The following notes are intended to give a complete record of chemical work to the present date on the rocks of the English Lake District, that name being employed in an extended sense to include the Lake District proper, together with the Lower Palæozoic inliers of Edenside, Sedbergh, and Ingleton, which belong to the same natural district. This compilation should have accompanied the Petrographical Notes prepared for the Keswick excursion, and published in the last number of these Proceedings (Vol. XIV., pp. 487-496), but it was not completed in time to be included there. Most of the items have appeared in an article published in "The Naturalist" for 1899, but I have now added a number of supplementary references to bring the list down to date, and have rearranged the whole to correspond with the notes already published in these Proceedings.

I give first a summary of the literature of the subject. Then follows the list of analyses, partial analyses, and silica determinations, the silica percentage being quoted in each case as the readiest means of identification. To each record is appended the name of the analyst and, in parenthesis, the reference to the original publication. In the case of a number of silica determinations made by students of Owens College and the Yorkshire College, under the superintendence of Dr. A. Harden and Dr. J. B. Cohen respectively, these latter names are cited as the authorities.

References.

(I.) Binney, Mem. Lit. Phil. Soc. Manch. (1871), Ser. 3, Vol. IV., p. 93.

(II.) Ward, Quart. Journ. Geol. Soc. (1875), Vol. XXXI., pp. 408, 411.

(III.) Ward, *ibid.*, p. 597.
(IV.) Ward, *ibid.* (1876), Vol. XXXII., pp. 5, 7, 22-24.
(V.) Ward, Geol. N. Part Engl. Lake Distr., Mem Geol. Sur. (1876), pp. 16, 18, 28.
(VI.) Ward, Monthly Micro. Journ. (1877), Vol. XVII., p. 246.
(VII.) Bonney and Houghton, Quart. Journ. Geol. Soc. (1879), Vol. XXXV., pp. 165-179.
(VIII.) Kendall. J. D., Trans. Manch. Geol. Soc. (1884), Vol. XVII., p. 295.
(IX.) Bonney, Geol. Mag. (1885), p. 80.
(X.) Kendall, P. F., Trans. Manch. Geol. Soc. (1889), Vol XX., p. 145.
(XI.) Groom, Quart. Journ. Geol. Soc. (1889), Vol. XLV., p. 298.
(XII.) Stock, Naturalist (1889), p. 304.
(XIII.) Harker and Marr, Quart. Journ. Geol. Soc. (1891), Vol. XLVII., pp. 275-302.
(XIV.) Hutchings, Geol. Mag. (1891), pp. 536-544.
(XV.) Hutchings, *ibid.* (1892), pp. 154-161, 218-228.
(XVI.) Harker and Marr., Quart. Journ. Geol. Soc. (1893), Vol. XLIX., p. 361.
(XVII.) Postlethwaite, *ibid.*, p. 533.
(XVIII.) Hutchings, Geol. Mag. (1894), p. 42.
(XIX.) Harker, Quart. Journ. Geol. Soc. (1894), Vol. L., pp. 321, 323.
(XX.) Harker, *ibid.* (1895)., Vol. LI., pp. 129-131, 140, 141.
(XXI.) Hutchings, Geol. Mag. (1895), p. 316.
(XXII.) Thomas, Journ. Roy. Inst. Brit. Architects (1896), Ser. 3, Vol. III., p. 196.
(XXIII.) Harker, Naturalist (1899), pp. 53-58, 149-154.
(XXIV.) Reade and Holland, Proc. Liverp. Geol. Soc. (1900), Vol. VIII., table p. 478.
(XXV.) Reade and Holland, *ibid.* (1901), Vol. IX., table p. 127.

(XXVI.) Rutley, Quart. Journ. Geol. Soc. (1901), Vol. LVII., p. 36.

(XXVII.) Harker, Geol. Mag. (1894), p. 553.

Skiddaw Slate Series.

(1). 54.480 (anal.). Altered Skiddaw Slate, summit of Red Pike, near the Buttermere granophyre: Hughes (IV.).

(2). 65.725 (anal.). Chiastolite-slate, How Gill, Skiddaw: Hughes (IV.).

(3). 54.448 (anal.). Spotted schist, Skiddaw Forest: Hughes (IV.).

(4). 53.174 (anal.). Mica-schist, close to Skiddaw granite, Sinen Gill: Hughes (IV.).

(5). 56.76 (anal.). Skiddaw slate, ? locality: Kendall (VIII.).

(6). 79.92 (anal.). Grit in Skiddaw Slates, Robin Hood, Bassenthwaite: Hellon (XVII.).

(7). 54.9 and 54.8 (silica). Lava in Skiddaw Slates, Scale Force, Crummock: MacFarlane and Thomas (XXIII.).

Falcon Crag Andesite Group.

(8). 54.5 and 54.2 (silica). Lava with porphyritic augite, base of No. 5 of Ward's section, E. of summit of Falcon Crag, Borrowdale: MacFarlane and Thomas (XXIII.).

(9). 60.718 (anal.). Pyroxene-andesite, No. 6 of section, Brown Knotts: Hughes (II.).

(10). 59.511 (anal.). Pyroxene-andesite, No. 12 of section, Iron Crag: Hughes (II.).

(11). 61.2 and 61.5 (silica). Pyroxene-andesite, base of No. 10 of section, above Falcon Crag: MacFarlane and Thomas (XXIII.).

(12). 54.6 (silica). Cleaved agglomerate (slate), Borrowdale quarries: Garwood (XXIII.).

(13). 58.65 (silica). Pyroxene-andesite, Pooley, Ullswater: Garwood (XXIII.).

Also, doubtfully assigned to this group:—

(14). 59.87 (anal.). Andesite, "Greystone" boulder, Manfield near Darlington: Stock (XII.).

Eycott and Ullswater Basalt Group.

(15). 53.40 and 52.73 (silica). Hypersthene-basalt, with large porphyritic felspars, No. 4 of Ward's section, Eycott Hill: Cooksey (IX.).

(16). 53.300 (anal.). Hypersthene-basalt, microporphyritic. No. 12 of section: Eycott Hill, Hughes (VI.).

(17). 52.600 (anal.). Hypersthene-basalt, very compact. No. 13 of section, Eycott Hill: Hughes (VI.).

(18). 51.100 (anal.). Hypersthene-basalt, No. 15 of section, Eycott Hill: Hughes (VI.).

(19). 54.3 and 54.9 (silica). Lava with porphyritic augite. Mousegill quarry, Wilton Fell, near Egremont: MacFarlane and Thomas (XXIII.).

(20). 48.68 (silica). Porphyritic basalt of Eycott type, near Devil's Slidegate, Illgill Head, Wastwater: Harden (XXIII.).

(21). 52.95 (silica). Porphyritic basalt, Brimfull Beck, Overbeck, Wastwater: Garwood (XXIII.).

(22). 51.35 (silica). Vesicular basalt with porphyritic augite, Scarth Gap, near summit of pass: Hutchings (XIV.).

(23). 56.2 (silica). Highly-metamorphosed lava resting on Eskdale granite, Great Barrow, Boot: Harden (XXIII.).

(24). 55.7 and 55.9 (silica). From same locality: MacFarlane and Thomas (XXIII.).

(25). 52.6 (silica). Basalt, Galleny Force, Greenup Gill: Garwood (XXIII.).

(26). 57.4 and 57.1 (silica). Compact lava, about $\frac{1}{4}$ mile N.W. of Castle Crag, Borrowdale: MacFarlane and Thomas (XXIII.).

(27). 53.45 (silica). Cleaved tuff, slate, Honister quarries: Garwood (XXIII.).

(28). 52.34 (anal.). Cleaved tuff, green slate, Honister Pass: Holland (XXV.).

(29). 53.50 (anal.). Cleaved tuff, green slate, Honister Pass: Holland (XXV.).

(30). 54.02 (anal.). Cleaved tuff, olive-green slate, Honister Pass: Holland (XXV.).

(31). 53.45 (silica). Porphyritic basalt of Eycott type, Randal Beck, Mardale: Garwood (XXIII.).

(32). 54.6 (silica). Porphyritic basalt, Gatescarth Pass, near Mardale: Garwood (XXIII.).

(33). 56.95 (silica). Crushed and cleaved porphyritic lava, Fordingdale Force, Measand Beck, Haweswater: Garwood (XXIII.).

(34). 50.75 (silica and lime). Basalt, Low Fell, Shap: Garwood (XIII.).

(35). 50.90 (silica and lime). Basic tuff, Low Fell, Shap: Garwood (XIII.).

(36). 27.88 (anal.). Cleaved calcareous tuff, green slate, Buttermere: Holland (XXIV.).

The next thirteen rocks, though apparently belonging to this group, seem to present andesitic rather than basaltic characters.

(37). 59.151 (anal.). Andesite, Lingmell Beck, Wastdale: Hughes (III.).

(38). 57.55 (silica). Augite-andesite, above Nan Bield: Hutchings (XIV.).

(39). 52.45 (silica). Much altered andesite, Easedale Tarn, right side: Hutchings (XIV.).

(40). 60.75 (silica). Andesite, Easedale Tarn, left side: Hutchings (XIV.).

(41). 51.6 (silica). Much altered andesite, roadside quarry between Seatoller and Seathwaite: Hutchings (XIV.).

(42). 53.55 (silica). "Andesitic basalt," Seatoller Fell: Hutchings, (XIV.).

(43). 62.43 (silica). Andesite, near Ullswater, on road to Matterdale: Hutchings (XIV.).

(44). 61.45 (silica). Andesite, N. slope of Stoneside Fell, Bootle: Garwood (XXIII.).

(45). 62.95 (silica). Porphyritic andesite (possibly intrusive), Whiteside Bank, Helvellyn: Garwood (XXIII.).

(46). 69.673 (anal.). Tuff, partly metamorphosed, Base Brown, near Borrowdale: Hughes (III.).

(47). 68.421 (anal.). Metamorphosed breccia, Slight Side, near Eskdale: Hughes (III.).

(48). 69.48 (silica). Compact rock with lenticular streaky structure, N.E. slope of Illgill Head, Wastwater: Harden (XXIII.).

(49). 66.95 (silica). Crushed garnetiferous lava, Frith Wood, Rosthwaite, Borrowdale: Garwood (XXIII.).

The three rocks next following are of acid composition, though intercalated in the basaltic group.

(50). 73.45. Rhyolite, upper part of Measand Beck, Haweswater: Garwood (XXIII.).

(51). 82.25. Rhyolite, somewhat altered, $\frac{1}{4}$ mile S.E. of Walla Crag, Haweswater: Garwood (XXIII.).

(52). 76.95. Breccia, Frith Wood, Rosthwaite: Garwood (XXIII.).

Scawfell Tuff and Breccia Group, with the Kentmere-Coniston Slate-Band.

(53). 56.60 (silica). Hornstone (altered fine tuff), Hanging Knott, Bow Fell: Garwood (XXIII.).

(54). 63.1 (silica). Hornstone (altered fine tuff), upper part of Eskdale: Harden (XXIII.).

(55). 58.69 (anal.). Andesite, Thornthwaite Crag: Cohen (XIV.).

(56). 66.59 (silica). Dark garnetiferous rock, a little south of summit of Scawfell: Harden (XXIII.).

(57). 69.22 (anal.). Cleaved tuff (ash-slate), insoluble portion, Mosedale, near Shap: Patterson (XV.).

(58). 74.88 (anal.). Cleaved tuff (ash-slate), insoluble portion, below reservoir, Kentmere: Patterson (XV.).

(59). 61.75 (silica). Cleaved tuff (ash-slate), Grasmere, quarry; Patterson (XV.).

(60). 77.40 (silica). Insoluble portion of the same rock: Patterson (XV.).

(61). 50.88 (anal.). Cleaved tuff, "green Westmoreland slate," probably from Tilberthwaite: Vogt (XXII.).

(62). 61.25 (silica). Cleaved tuff, slate, Tilberthwaite quarries: Garwood (XXIII.).

(63). 50.16 (anal.). Cleaved tuff, dark green slate, Tilberthwaite: Holland (XXV.).

(64). 52.67 (anal.). Cleaved tuff, green slate, Elterwater: Holland (XXV.).

(65). 80.52 (anal.). Insoluble portion of the same rock: Holland (XXV.).

Shap Andesite Group.

(66). 59.95 (silica and lime). Amygdaloidal augite-andesite, between Wasdale Pike and Great Yarlside: Garwood (XIII., XVI.).

(67). 65.80 (anal.). Andesite, "near Coniston": Cohen (X.).

Also two rocks doubtfully referred to this group:—

(68). 63.60 (anal.). Andesite, boulder, Oxford Street, Manchester: Cohen (X.).

(69). 61.95 (silica). Crushed and cleaved porphyritic lava, Crags Mill, Shap: Garwood (XXIII.).

Shap Rhyolite Group.

(70). 53.10 (anal.). Basic tuff, highly metamorphosed, close to Shap granite, Wasdale Pike: Hutchings (XXI.).

(71). 75.95 (partial anal.). Spherulitic rhyolite, Stockdale: Garwood (XIII.).

(72). 76.95 (partial anal.). Nodular rhyolite, metamorphosed, close to Shap granite, Wasdale Head Farm: Garwood (XIII.).

(73). 83.8 (silica). Rhyolite, probably with secondary quartz, locality not specified: Tate (XXIII.).

(74). 69.00 (anal.). Soda-rhyolite, north end of Dufton Pike, Eden Valley: Holland (XXVI.).

(75). 71.05 (anal.). Rhyolite, Dufton Pike: Holland (XXVI.).

Coniston Flags.

(76). 58.55 (anal.). Lower Coniston (or Brathay) Flags, Wasdale Beck, near Shap Wells: Hutchings (XVIII.).

(77). 61.05 (anal.). The same rocks highly metamorphosed, near the Shap granite, Wasdale Beck, ¾ mile above Shap Wells: Hutchings (XVIII.).

Intrusive Rocks: Older Suite.

(78). 71.442 (anal.). Granophyre of Buttermere mass, Scale Force: Hughes (IV.).

(79). 67.180 (anal.). Microgranite of St. John's Vale intrusion, Threlkeld: Hughes (IV.).

(80). 60.45 (silica). Quartz-porphyrite ("quartz-andesite or dacite"), between Greenburn and Wythburn: Hutchings (XIV.).

(81). 61.15 (silica). Porphyry ("trachyte"), Shap Wells plantation: Hutchings (XIV.).

(82). 64.5 and 63.9 (silica). Garnetiferous porphyrite (?), doubtfully assigned to this place, near Dock Tarn, E.N.E. of Stonethwaite Church, Borrowdale: MacFarlane and Thomas (XXIII.).

(83). 48.42 (anal.). Diabase, Robin Hood, Bassenthwaite: Hellon (XVII.).

(84). 45.65 (silica). Diabase, above Easedale Tarn, towards Langdale: Hutchings (XIV.).

(85). 45.54 (anal.). Diabase, Gleaston, Low Furness: Roscoe (I.).

(86). 50.96 (anal.). Another specimen of the same: Roscoe (I.).

(87). 51.10 (anal.). Another specimen of the same: Roscoe (I.).

The age and geological relations of these last three rocks are doubtful.

Intrusive Rocks: Younger Suite.

(88). 73.573 (anal.). Eskdale granite, S. of Great How: Hughes (III.).

(89). 75.223 (anal.). Skiddaw granite, White Gill: Hughes (IV.).

(90). 77.26 (silica). Skiddaw granite, bed of Caldew, 300 yards above Grainsgill: Brend and Craig (XX.).

(91). 78.13 (silica). Greisen, near foot of Brandy Gill: Harden (XX.).

(92). 80.36 (anal.). Greisen, Combe Height, 250 yards S. of Grainsgill: Spencer (XX.).

(93). 68.55 (anal.). Shap granite: Cohen (XIII.).

(94). 65.41 (anal.). Large porphyritic felspars of the same rock: Cohen (XIII.).

(95). 68.89 (anal.). Ground-mass of the same: Cohen (XIII.).

(96). 69.78 (silica). Shap granite: Garwood (XIII.).

(97). 56.95 (silica). Dark, relatively basic patch in the same rock: Garwood (XIII.).

(98). 44.44 (anal.). Mica-lamprophyre ("minette-felsite"), dyke, $\frac{3}{4}$ mile from Windermere Station: Houghton (VII.).

(99). 46.17 (anal.). Hornblende-mica-lamprophyre ("diorite, micaceous"), dyke, Gill Bank, $1\frac{1}{4}$ miles N.N.E. of Staveley: Houghton (VII.).

(100). 49.52 (anal.). Hornblende-lamprophyre ("diorite, micaceous"), Stile-end Farm, between Kentmere and Long Sleddale: Houghton (VII.).

(101). 61.12 (anal.). Mica-lamprophyre ("minette-felsite"), Kendal road, 250 yards from third milestone: Houghton (VII.).

(102). 48.57 (anal.). Mica-lamprophyre ("minette-felsite"), dyke on railway, W. of Docker Garth: Houghton (VII.).

(103). 58.34 (anal.). Mica-lamprophyre ("minette-felsite"), dyke S. of Haygarth, Docker Fell, No. I.: Houghton (VII.).

(104). 47.88 (anal.). Mica-lamprophyre ("minette-felsite"), dyke S. of Haygarth, Docker Fell, No. II.: Houghton (VII.).

(105). 32.31 (anal.). Mica-lamprophyre (" minette-felsite "), lowest dyke, Helm Gill, near Sedbergh : Houghton (VII.)

(106). 47.2 (anal.). Mica-lamprophyre, the most southerly dyke, Helm Gill : Tate (XXIII.).

(107). 47.1 (anal.). Duplicate analysis of the preceding : Tate (XXIII.).

(108). 46.34 (anal.). Another specimen from the same dyke : Tate (XXIII.).

(109). 58.99 (anal.). Mica-lamprophyre, E. bank of Doe, Storrs, Ingleton (" Phillips' dyke ") : Tait (XXIII.).

(110). 59.46 (silica). Carrock Fell gabbro (quartz-gabbro), White Crags : Brend and Craig (XIX.).

(111). 57.7 (silica). Carrock Fell gabbro (quartz-gabbro), 350 yards S. of White Crags : Brend and Craig (XIX.).

(112). 56.656 (anal.). Carrock Fell gabbro (quartz-gabbro), White Crags : Hughes (IV.).

(113). 53.9 (silica). Carrock Fell gabbro (quartz-gabbro), precise locality not specified : Tate (XXIII.).

(114). 53.50 (anal.). Carrock Fell gabbro (quartz-gabbro), roadside, 150 yards N.N.W. of Chapel Stone : Barrow (XIX.).

(115). 50.22 (silica). Carrock Fell gabbro, 600 yards S.W. by S. of White Crags : Brend and Craig (XIX.).

(116). 50.0 (silica). Carrock Fell gabbro (quartz-gabbro), same locality as (114) : Cohen (XIX.).

(117). 47.11 (silica). Carrock Fell gabbro, 120 yards N. of summit of White Crags : Brend and Craig (XIX.).

(118). 44.14 (silica). Carrock Fell gabbro, basic variety, top of cliff above Mosedale, S. edge of mass : Brend and Craig (XIX.).

(119). 43.4 (silica). Carrock Fell gabbro, basic variety, gill $\frac{3}{8}$ mile N.W. of Swineside, S. edge of mass : Cohen (XIX.).

(120). 33.4 (silica). Carrock Fell gabbro, highly basic variety, lowest part of Furthergill, N. edge of mass : Cohen (XIX.).

(121). 32.53 (anal.). Carrock Fell gabbro, highly basic variety, upper part of Furthergill, N. edge of mass: Barrow (XIX. and XXIII.).

(122). 77.38 (silica). Carrock Fell granophyre, below Scurth and 500 yards W.N.W. of Stone Ends: Brend and Craig (XX.).

(123). 75.3 (silica). Carrock Fell granophyre, in peat-moss S. of Drygill Head: Cohen (XX.).

(124). 71.60 (anal.). Carrock Fell granophyre, 100 yards E. of summit: Barrow (XX.).

(125). 69.044 (anal.). Carrock Fell granophyre, summit of Carrock Fell: Hughes (IV.).

(126). 60.0 (silica). Carrock Fell granophyre, modified by admixture of gabbro material, close to gabbro contact, Furthergill Sike: Cohen (XX.).

(127). 58.26 (silica). Carrock Fell granophyre, same locality as the preceding: Brend and Craig (XX.).

(128). 53.63 (anal.). Spherulitic tachylyte, vein cutting the Carrock Fell gabbro: Adie (XI.).

(129). 59.8 (silica). Variolitic andesite, dyke cutting Carrock Fell granophyre: Cohen (XXVII.).

[*Note added in the proof.* A paper by the late E. E. Walker, read before the Geological Society of London, December 2nd, 1903, and not yet published, contains eleven analyses and sixteen silica-determinations.]

ON SOME NEW SPECIES OF FOSSIL FISH FROM THE MILLSTONE GRIT ROCKS, WITH AN AMENDED LIST OF GENERA AND SPECIES.

BY EDGAR D. WELLBURN, L.R.C.P., F.G.S., ETC.

INTRODUCTION.

Since " A List of the Fish Fauna of the Millstone Grit Rocks " —by the writer—appeared in the *Geological Magazine* in 1901,* fresh material has come to hand which makes a slight revision of the list in one respect necessary, whilst on the other hand, three new fish-bearing localities are added, and also several genera which are new to these rocks.

REMARKS ON FISH REMAINS.

ICHTHYODORULITES.

Ctenacanthus major Agassiz.

Mr. Barns, F.G.S., of Manchester, records† *C. tenuistriatus* Davis (*Syn C. major* Agassiz) as occurring in these rocks at Netherly Quarry, Pule Hill, Marsden.

Oracanthus Milleri Agassiz.

The writer has seen a fragment from Pule Hill, Marsden, which he refers to this fish.

Family : Rhizodontidæ.

Genus : *Strepsodus.*

S. sauroides Binney.

The writer has found remains of this fish at Pule Hill and has also seen scales in the collection of Mr. Barns, F.G.S., from the same locality.

* Geol. Mag, Dec. IV., Vol. XVIII., pp. 216-222.

† Trans. Manch. Geol. Soc., Part VII., Vol. XXV.

Genus: *Rhizodopsis.*

R. sauroides Williamson.

Remains (scales, &c.) of this fish are in the collection of Mr. Barns, and also in that of the writer, from Pule Hill. Mr. Peter Whalley, of Colne, Lancashire, has also found remains of the fish at Antley Gate, near Colne, Lancashire.

Family: Osteolepidæ.

Genus: *Megalichthys.*

M. Hibberti Agassiz.

The writer has seen well-marked remains of this fish, from Antley Gate, Lancashire, collected by Mr. Whalley.

Family: Cœlacanthidæ.

Genus: *Cœlacanthus.*

C. summiti sp. nov.

Type: Imperfect crushed fish in author's collection.*

DESCRIPTION.—Of the head bones, the operculæ and angular bone of the mandible are ornamented with ridges, which, on the operculum, run upwards from the inferior border in an arched manner parallel to the anterior and posterior borders of the bone, which borders form a broad and evenly arched outline, the posterior arm of the arch being slightly longer than the anterior; the bone is one-third higher than broad. On the other opercular bones and on the angular bone of the mandible, the ridges run more or less parallel to the superior border of the bones. The jugular plates are rather more than three times as long as broad, the greatest width being at a point a little in advance of the meeting of the middle and posterior thirds of the bone; behind this point the plate gradually narrows to a rounded posterior extremity, whilst in front they more quickly taper to a moderately fine point. The bones are ornamented with ridges, which radiate from the centre in all directions.

The vertebra is represented by neural and hæmal arches and spines of the ordinary cœlacanthian form.

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* Besides the type, the writer has several more imperfect specimens which show various portions of the fish.

Swim bladder not well seen.

Scales are moderately pointed, and are ornamented with fine regular ridges which somewhat converge behind.

Remarks.—From the form, proportion, and ornamentation of the head bones and also the sculpture of the scales. I consider the species to be new, and propose the specific nomen "Summiti," from the locality where I found the type.

Form and Loc.: D Shales. Middle Grits. at Summit, and Antley Gate, near Colne, both in Lancashire.

Family: Palæoniscidæ.

Genus: *Rhadinichthys.*

R. Monensis Egerton.

The writer has found well-marked remains of this fish in two separate localities, this being a new record for the Millstone Grit rocks.

R. elegans sp. nov.

Type and many fragmentary specimens in author's collection.

Description.—Of the bones of the head, the opercular and scapular are ornamented with moderately fine ridges, which run more or less parallel to the long axes of the bones. On the mandible they have a similar arrangement, with the exception that a few of the more superior ones turn upwards to cut the superior border of the bone at an acute angle. The scales are large and have a highly characteristic ornamentation, viz., the principal flank ones are sculptured by well-marked, closely arranged, ganonine-coated ridges, which have the following arrangement, viz., they commence at the anterior two-thirds of the superior margin of the scale, in a regular series; they then run down parallel to the anterior border, and turning round in succession at the anterior inferior angle, they sweep across the scale parallel to the inferior border. This arrangement leaves a space at the posterior superior corner of the scale, which is sculptured by ridges which run more or less obliquely in an irregular manner. On the anterior and posterior flank scales the sculpture is of the same general pattern, but the ridges tend to run in a more oblique manner, the turn at the anterior inferior angle thus becoming more obtuse. On the narrow ventral scales this obliquity of the ridges is much more marked. The enlarged scales anterior to the anal fin have a very characteristic sculpture. the ridges running inwards and backwards to meet one another up the central axis of the scale. No fins are shown. but certain scattered fin rays would point to the fact that they were distantly articulated.

Remarks.—From the general character of the scales—they being "large and thin"—also from the general resemblance of their sculpture to that of *R. fusiformis* Traq., I place the fish in the above genus. As regards specific distinction, although in scale sculpture this species somewhat resembles that of *R. fusiformis* Traq.. still in comparing the two the distinction is at once apparent. On account of the "handsome" character of scale sculpture. the specific nomen "elegans" is proposed.

Elonichthys obliquus sp. nov.

Type and many fragmentary specimens are in the author's collection.

Description.—Length about 15 cm.

The head bones are ornamented with well-marked, slightly undulating ridges which frequently branch; on the opercular bones they run more or less obliquely across the bones; on the maxilla the sculpture is very characteristic, viz., the ridges run for some distance parallel with the upper margin of the bone; they then turn downwards and run with frequent branching towards the dentary margin where they become very numerous, and some being divided transversely, there is here an appearance of tuberculation; on the mandible the ridges run obliquely upwards and forwards to cut the dentary margin at an acute angle. On the bones of the shoulder girdle the ridges run in a direction more or less parallel to the long axes of the bones. The scales are of moderate size; those of the flank are higher than broad; posteriorily they become more oblique and equilateral; whilst towards the dorsal and ventral surfaces they are low and broad. Their ornamentation consists of well-marked ridges which run transversely across the scale from the anterior border, but below a point about the centre of this border they become more and more oblique, the lowermost ones running downwards for some little distance more or less parallel to the anterior border, then turning above the anterior inferior angle they run obliquely across the scale to the posterior border, whilst the lowermost ridges run parallel to the inferior border. The ridges frequently branch, and their number is often increased, in the posterior half of the scale, by intercalations. On some of the flank scales the sculpture is rendered more ornate by finer ridges, which run across the scale parallel to and between the coarser ridges. Further back on the body the sculpture assumes a more oblique direction, the ridge running more or less parallel to a line drawn from the anterior superior angle to the posterior inferior angle. On the lower ventral scales the sculpture is more regular in pattern, the ridges mostly running parallel to the superior and inferior borders; there is also frequent intercalation of shorter ridges on the posterior half of the scale. The posterior margin of the principal flank scales are denticulated. The fins are only represented by scattered rays which are somewhat distantly articulated, and have a well-marked longitudinal furrow.

Remarks.—At a first glance this fish might be mistaken for *E. Aitkeni* Traquair, but on a closer examination it is seen to differ from that species in the more oblique and elaborate nature of its scale sculpture, and also in the fact that the sculpture on the mandible differs from that of Dr. Traquair's species in the fact that in the latter fish "the ridges ran more or less parallel with the upper and lower margins of the bone," whereas in the present fish they ran upwards and forwards, cutting the dentary margin at an acute angle.

I place the fish in the above genus on account of its great resemblance to *E. Aitkeni* Traquair, and because of the general characters of its scales, giving it the specific nomen "obliquus" on account of its scale sculpture.

Form. and Loc.: D Shales, Middle Grits, at Wadsworth Moor, Marsden, Ivy Clough, near Halifax, all in Yorkshire, also in D Shales, Middle Grits at Summit, and Antley Gate in Lancashire.

Elonichthys ornatus sp. nov.

Type (which is a crushed specimen showing the greater part of the body of the fish) and other more fragmentary remains are in the author's collection.

Description.—The head bones are ornamented with fine well-spaced, slightly-vermiculating ridges; on the mandible the lowermost ridges run forward parallel to the lower border of the bone, whilst the uppermost ones run forwards—the most anterior ones branching—and upwards to cut the dentary margin of the bone at a very acute angle.

The scales of the fish are sculptured in a very striking and beautiful manner, which varies somewhat on the various parts of the body, viz., on the principal flank scales the ornamentation is of a duplex pattern, viz., below a line drawn from the anterior superior angle to the posterior inferior angle are *well-marked* ridges which run, from the anterior border, downwards and backwards, converging towards the posterior inferior angle: above the diagonal line *fine* ridges which run in a more or less irregular manner towards the posterior border, whilst several very fine ridges run close to and parallel to the superior border. Further back on the flank there are often several fine ridges running parallel to the inferior as well as the superior margin, whilst between these the coarser ridges run in a more or less irregular manner towards the posterior border which appears to be somewhat serrated. On the lower ventral scales, there are firstly several well-marked ridges running obliquely downwards and backwards from the anterior to the inferior border, whilst behind these are—on the greater part of the scale—ridges which run posteriorily more or less parallel to the superior and inferior margins. The general character of the scale sculpture is continued far back towards the caudal region. The median dorsal scales are ornamented by ridges which run in a regular manner backwards and inwards—on each lateral half of the scale—to meet along the median line.

No fins—with the exception of some rays of the caudal—are seen. The rays of the caudal fin appear to have been somewhat distantly articulated.

REMARKS.—From the character of the scales—some of which somewhat resemble the scales of *E. robisoni* Tr., as figured by Dr. Traquair in Ganoid Fishes of British Carboniferous Formations, Part I., No. 2, Plate XIV., figs. 5 and 6, I place the fish in the above genus, giving it the specific designation "ornatus," as the fish is undoubtedly new to science.

Form. and Loc.: D Shales, Middle Grits, Summit, Lancashire.

Genus: *Platysomus*.

The writer has seen bones, scales, &c., which undoubtedly belong to this genus, but which were not sufficient to render any description as to species possible.

In conclusion the writer begs to state that, not only has he carefully compared the new species with the Fossil Fishes in the Natural History Section of the British Museum, etc., but he has also had the pleasure of showing them to Mr. John Ward, F.G.S., who quite agrees with him that they are new to science.

The writer's thanks are also due to Mr. Peter Whalley, of Colne, Lancashire, for his kindness in placing in his hands —for description—the series of fish remains collected by him at Antley Gate, Lancashire.

TABLE OF GENERA AND SPECIES WITH THEIR DISTRIBUTION IN THE MILLSTONE ROCKS.

	D Shales, Middle Grits, Wadsworth Moor, Yorkshire.	D Shales, Middle Grits, Summit, Lancashire.	D Shales, Middle Grits, Marsden, Yorkshire.	D Shales, Middle Grits, Boulder Clough, near Halifax, Yorkshire.	D Shales, Middle Grits, Kiln House Wood, near Halifax, Yorkshire.	† D Shales, Middle Grits, Ivy Clough, near Halifax, Yorkshire.	† D Shales, Middle Grits, Halifax, Yorkshire.	D Shales, Middle Grits, Eccup, near Leeds, Yorkshire.	† D Shales, Middle Grits, Antley Gate, near Colne, Lancashire.	B Shales, Middle Grits, near Halifax, Yorkshire.	C Shales, Middle Grits, near Halifax, Yorkshire.	Rough Rock, near Halifax, Yorkshire.
Cladodus mirabilis Agassiz	*	?	...	...	...	...	...	...	...	...	...	...
Pristodus falcatus Davis	...	*	...	...	...	...	...	...	...	...	...	...
Helodus sp.?	...	*	...	...	...	...	...	...	...	...	...	...
Pleuroplax Rankinei Handk & Atthey ‡ ...	...	...	...	...	...	...	...	...	*	...	...	...
Psephodus minuta Wellburn	...	*	...	...	...	...	...	...	...	...	...	...
Pœcilodus Jonesii McCoy...	...	*	...	...	...	...	...	...	...	...	...	...
Orodus elongatus Davis	...	*	...	...	...	...	...	...	...	...	...	...
Acanthodes Wardi Egerton	*	*	?	*	*	*	*	*	*	...	...	...
Acanthodes striatus Wellburn	...	*	*	...	...	...	...	...	...	...	...	...
Acanthodes sp.?	...	...	*	...	...	...	...	...	...	...	...	...
Marsdenius summiti Wellburn (=*climatius* sp.?)§	...	*	*	...	...	...	...	...	...	...	...	...
Acondylacanthus sp.?	...	*	...	...	...	...	...	...	...	...	...	...
Ctenacanthus major Agassiz	...	...	*	...	...	...	...	...	...	...	...	...

† New fish-bearing localities. ‡ Species new to these rocks. § *Marsdenius summiti* = *climatius* sp.? of the author's previous list.

	D Shales, Middle Grits, Wadsworth Moor, Yorkshire.	D Shales, Middle Grits, Summit, Lancashire.	D Shales, Middle Grits, Marsden, Yorkshire.	D Shales, Middle Grits, Boulder Clough, near Halifax, Yorkshire.	D Shales, Middle Grits, Kiln House Wood, near Halifax, Yorkshire.	† D Shales, Middle Grits, Ivy Clough, near Halifax, Yorkshire.	† D Shales, Middle Grits, Halifax, Yorkshire.	D Shales, Middle Grits, Eccup, near Leeds, Yorkshire.	† D Shales, Middle Grits, Antley Gate, near Colne, Lancashire.	B Shales, Middle Grits, near Halifax, Yorkshire.	C Shales, Middle Grits, near Halifax, Yorkshire.	Rough Rock, near Halifax, Yorkshire.
Oracanthus Milleri Agassiz ‡	...	...	*	...	...	...	...	...	...	...	...	...
Euctenodopsis tenuis Wellburn	...	*	...	...	...	...	...	...	...	...	...	...
Strepsodus sulcidens Hand & Atthey	*	...	...	...	...	...	...	...	...	...	...	...
Strepsodus sauroides Binney ‡	...	...	*	...	...	...	...	...	...	...	...	...
Rhizodopsis sauroides Williamson	...	...	*	...	...	...	...	...	*	...	...	...
Megalichthys Hibberti Agassiz ‡	...	...	...	...	...	...	...	...	*	...	...	...
Cœlacanthus summiti sp. nov. ‡	...	*	...	...	...	...	...	...	*	...	...	...
Rhadinichthys monensis Egerton ‡	...	...	...	...	...	*	*	...	...	...	...	...
Rhadinichthys elegans Wellburn	...	*	...	...	...	...	...	...	*	...	...	...
Elonichthys Aitkeni Traquair	*	*	*	...	...	*	*	...	*	*	*	*
Elonichthys obliquus Wellburn	*	*	*	...	...	*	...	...	?	...	...	...
Elonichthys ornatus Wellburn	...	*	...	...	...	...	...	...	...	...	...	...
Acrolepis Hopkinsi McCoy	*	*	...	...	...	*	...	*	*	...	...	...
Platysomus sp. ? ‡	...	...	...	...	...	...	...	...	*	...	...	...

† New fish-bearing localities. ‡ Species new to these rocks.

RECORDS AND COMPARISON OF THREE DEEP BORINGS IN THE MILLSTONE GRITS AT HALIFAX.

BY WM. SIMPSON, F.G.S.

Three deep borings have been sunk in the dip slope of the Grit Rocks of Halifax in search of an increased supply of water during the past few years, and in return for such geological information as I have been able to give, I was allowed to watch the operations and make notes of the strata passed through.

Halifax is built on the Rough Rock, the top member of the Millstone Grit series.

At the lowest part of the town, a little to the east of the railway line, the Grit series pass under the Lower Coal Measures which form the bold escarpment and conspicuous physical feature to the east of the town. From here the Rough Rock, which has a general datum level of about 400 feet where it disappears under the Coal Measures, rises at an angle of about 2° to the west and north-west to over the 1,000 feet datum.

Further to the west and north-west of Halifax, Luddenden valley cuts through the various members of the Grit series, almost down to the Kinderscout rocks at the base.

On the easterly terraced sides of this valley, and on the moorlands to the north, the middle series of the Grit rocks are exposed, and doubtless gather a considerable amount of surface water, which following the dip, and directed and held by the impervious shales above and below, passes under Halifax at varying depths below the surface rocks.

The Rough Rock, as its name would suggest, is generally coarse in grain, very felspathic, and much jointed, and carries a good supply of water held up by the underlying shales. This water has been tapped to a considerable extent by wells in various parts of the town.

About fourteen years ago a High Level Railway was built in the upper part of the town, which necessitated a deep cutting in the Rough Rock, almost along the line of the strike of the beds. This cutting intercepted a considerable quantity of the water held by and passing through the sandrock, and seriously diminished the supply to be obtained from some of the wells cut into it lower down the dip slope, and it was to obtain further supplies that the borings described here were undertaken.

Messrs. Ward's and Hollingrake & Clegg's premises are situated in the upper part of the town, about 600 yards apart. and each on approximately the 700 feet datum.

Messrs. Ramsden's are lower down the slope, on the 500 feet datum, about three-quarters of a mile due east from Messrs. Ward's, and a mile to the south-east of Messrs. Hollingrake and Clegg's.

In the sections to scale accompanying these notes I have, for the purpose of correlation, drawn on the same plate the average section of these rocks given in the Memoirs of the Geological Survey of this district.

The two coal bands shown in this section are not specifically mentioned in the Memoirs, but are figured in the marginal section published with the one-inch geological map of the area.

It may be noted also, in reference to the Survey section, that it includes the whole series of the local Millstone Grits, with the exception of the Kinderscout Grit at the bottom of the series, and the shales between this Grit and the Sandrock A of the section. The Kinderscout Grit of this district is given as averaging 350 feet thick, and the shales which part it from Sandrock A 145 feet, making a total thickness for the whole series of 1,359 feet.

It will be obvious that in sections drawn to so small a scale it is impossible to mark all the minor changes. The Grits are notoriously very variable, and borings only a few yards apart would probably give slightly different results. Small and unimportant lenticular or wedge-like beds of shale part the sand-rocks here and there, and, similarly, shales have minor rock-bands within their mass which do not affect the more general divisions. Again, clayey or argillaceous shales may become more sandy or arenaceous, and pass without perceptible break into sandrock, or *vice versa*, so that it is frequently difficult to mark any clear line of division, or to decide the exact character or definition of the rock.

My object was to note the changes as clearly as I could, and to correlate each portion of the sections where possible with its position in the series.

Messrs. Ward's bore was sunk in 1898–9; their premises (the West End Dyeworks) are a little to the east of Queen's Road, and about midway from either end.

They had an existing well, 6 feet in diameter, sunk to a depth of 131 feet, from which they obtained a good supply of water, until the deep cutting for the High Level Railway across the dip slope higher up intercepted and diminished the amount available, and boring was undertaken in the hope of tapping supplies from lower beds.

The existing well tapped water held by the shales underlying the Rough Rock and its accompanying flagstones at the base—the gather ng ground for this water being the higher land extending towards High Road Well and Mount Tabor.

An $11\frac{1}{4}$ inches chisel bore was commenced at the bottom of the existing well, 131 feet from the surface; this was carried down for 276 feet, and a $9\frac{1}{2}$ inch bore for a further 101 feet, at which depth, 508 feet from the surface, operations ceased.

The samples of rocks preserved were, of course, broken very fine by the boring chisel, and are consequently only of use lithologically, any palæontological traces being quite unrecognisable.

The following is a slightly abridged record of the rocks passed through:—

	Depth Bored. ft.	in.	Total depth from surface. ft.	in.
The well, 6 feet diameter, may be taken to be sunk entirely in and through the Rough Rock (the top rock of the Millstone Grit series) and the accompanying Flag Rock at its base; the water would be held by the Black Shale below			131	0
1. Black Shale	6	0	137	0
2. Hard Rock Bind	7	0	144	0
3. Black Shale	0	6	144	6
4. Hard Light Rock Bind	5	6	150	0
5. Black Shale	4	0	154	0
6. Hard Light Shale	3	3	157	3
7. Blue Shale	1	0	158	3
8. Light Rag	3	9	162	0
9. Blue Shales and Rag	13	6	175	6
10. Light Shales	1	8	177	2
11. Blue and Black Shales, with occasional admixture of Light Rag	131	4	308	6
12. Fine Hard White Siliceous Sandstone, with carbonaceous matter in upper part	16	6	325	0
13. Black Shales	11	0	336	0
14. Hard White Grit, with slight admixture of carbonaceous matter, as if a small Coal Band had been passed through at top	26	0	362	0
15. Darker Rock, not quite so fine and hard as above	64	0	426	0
16. Black Shales, with thin bands of Sandrock	36	6	462	6
17. Impure Coal	1	0	463	6
18. Hard Siliceous Rock, with carbonaceous admixture, in all probability "Galliard"	44	6	508	0

Here work ceased; the bore was not through the Galliard, which is an extremely trying rock to cut, and the results did not justify further boring. Water was obtained, but in insufficient quantity, and at too low a level to be economically serviceable.

The following water tests were made on June 19th, 1899. Before commencing to withdraw, the water stood at a level of 159 feet from the surface. A shell was let down, 6 feet long and 10 inches diameter, holding 20 gallons, and was filled and withdrawn twenty times during the first hour, removing 400 gallons; the water level sank 29 feet to 188 feet from the surface.

The next 35 minutes the shell was used 32 times, and the water level fell a further 7 feet, at which it remained whilst 160 gallons were drawn in 25 minutes more.

After ceasing to draw, the water rose again as follows:—

	ft.	in.
During the first fifteen minutes	14	6
,, second ,, ,, ...	8	0
,, third ,, ,, ...	4	6
,, fourth ,, ,, ...	1	6
	28	6

to 166 feet from the surface.

The Survey Memoirs of this district give the average thicknesses of the various upper members of the Millstone Grits, descending from the Rough Rock, as follows:—

	ft.	in.
Rough Rock	108	0
Flags, or Second Grit	33	0
Shales	153	0
White Sandrock, the top beds of the Third or Middle Grits	127	0
	421	0

The section revealed by the boring conforms most remarkably to this classification, bearing in mind that the survey is an average and deductive section. We get 131 feet to the base of the Flags and Rough Rock; the Survey average is 141 feet. We get 200 feet of shales if we class No. 12 with the shales, against 153 feet in the Survey. It may be, however, that No. 12 is part of the White Sandrock, which has 11 feet of shale parting here, or No. 12 may be "Galliard"; the boring samples are too broken up to judge. If, however, we group No. 12 with 13, 14, and 15, it would give us shales 177 feet, and sandrock with shale parting 117 feet. The most remarkable coincidence is, however, the total depth; the Survey calculations are 421 feet, our section to the base of No. 15 gives us 426 feet. This of course is a mere coincidence, but it is remarkable and interesting.

As to the absence of water in quantity, and its low level of 159 feet from the surface, the works where the bore was sunk are about on the 700 feet datum level; the base of Sandrock, No. 15, would therefore be about 270 feet above sea level, and the water surface about 540 feet. The outcrop of this Sandrock in Luddenden Dean would be at an elevation, roughly, of 650 to 700 feet, so that unless the rocks were very heavily charged with water, an unlikely assumption, considering the severe slopes of Warley and Luddenden, and the amount of drainage to the stream in the valley, the water level could not be expected to rise much higher; and when this rock, No. 15, did not furnish a supply, it was considered useless to go lower, or at least highly unlikely that any lower supply could be obtained to be of sufficiently economical service.

Messrs. Ramsden commenced boring operations in October, 1901, and finished in June, 1902; their object being attained in securing a fairly satisfactory increase of water supply. The boring was commenced at the bottom of an existing well situate on their premises in St. John's Lane. The well is 50 feet deep and 6 feet in diameter, the surface being about on the 500 feet datum level. A $10\frac{1}{4}$ inches diamond core bore, giving a central core of 9 inches was first used, and was reduced to 9 inches at 150 feet from the surface.

The following is a more detailed description of the bore than can be given in the figured section :—

	STONE TROUGH BREWERY.	ft.	in.	Total depth from surface. ft.	in.
	To bottom of existing well	50	0	50	0
1.	Rough Rock	74	0	124	0
	At 124 feet (the probable base of the Rough Rock) the rock was much stained, worn, and rubbly in character, and showed every evidence of being the horizon of a considerable water run.				
2.	Blue-grey Shales	11	0	135	0
3.	Grey raggy Sandrock	3	0	138	0
4.	Grey Shales	11	0	149	0
5.	Fine Sandrock	8	0	157	0
6.	Grey Shales with small Sandrock bands	9	0	166	0
7.	Flaggy Sandrock	10	0	176	0
8.	Grey arenaceous Shales	12	0	188	0
9.	Sandrock	8	0	196	0
10.	Grey and Dark Shales	124	0	320	0
	At 277 feet and 290 feet nodular bands of Ironstone were passed through, and at about 314 feet there was a very fossiliferous horizon with small crushed *Goniatites* and *Aviculopectens*.				
11.	Coal Band	0	5	—	
12.	Galliard	2	7	323	0
	This came out like an ordinary soft, soapy, Fireclay, but quickly hardened on exposure into the characteristic hard Galliard.				
13.	Successions of Grey Rag and fine Sandrocks	49	0	372	0
14.	Dark Shales (with nodular Ironstone bands) passing into black carbonaceous Shales	89	0	461	0
15.	Light free Sandrock in upper part, coarser below	76	0	537	0

		ft.	in.	Total depth from surface. ft.	in.
16.	Dark blue-grey Shales, with nodular Ironstone bands	50	0	587	0
17.	Coal	0	4	—	
18.	Fireclay	4	8	592	0
19.	Shale	3	0	595	0
20.	Coarse Sandrock, with thin carbonaceous lines and impressions	6	0	601	0
21.	Hard, quartzitic Sandrock	3	0	604	0
22.	Fireclay, with plant markings.. .. A fine impression of *Cyclopteris oblata* was revealed by a broken section of the core here.	0	6	—	
23.	Very hard, white, quartzitic Rock, very micaceous in parts	12	6	617	0
24.	Hard, dark Shales with hard, white micaceous Sandrock bands	18	0	635	0

Here water tests were made, and it was found that with the pipe at 200 feet from the surface the supply did not fall with continuous pumping below that level, and that some 34,000 gallons could be obtained daily; consequently boring operations ceased.

Messrs. Hollingrake & Clegg's premises, in Miall Street, are on about the 700 feet datum, higher up the dip slope of the same beds, about a mile to the north-west of Messrs. Ramsden's, and about 600 yards or so due north of Messrs. Ward's.

Here there was an existing well 6 feet in diameter, sunk to a depth of 283 feet, and boring was undertaken to increase the water supply.

Work was begun in September, 1901, discontinued owing to the pumps being out of order in October, and recommenced in July, 1902, with a bore $9\frac{1}{8}$ inches in diameter, which was reduced at 477 feet from the surface to $8\frac{1}{8}$ inches and gave a core as follows:—

Miall Street Bore.

		ft.	in.	Total depth from surface. ft.	in.
	Existing Well, 6 feet in diameter ..	283	0	283	0
	Chopped out for foundations	2	0	285	0
1.	Dark-blue Shales	26	8	311	8
2.	Coal	0	3	—	
3.	Grey Shale	2	0	313	11
4.	Galliard and fine Sandrock	11	8	325	7
5.	Shales	12	11	338	6
6.	Hard, white Sandrock	34	2	372	8
7.	Hard Grey Rag	8	0	380	8
8.	Dark Shales	91	4	472	0
9.	Sandrock	23	4	495	4
10.	Hard, grey, arenaceous Shales	36	8	532	0
11.	Dark, fossilferous Shales	13	5	545	5
12.	Grey Rag and Sandrock	6	1	551	6
13.	Grey Shale	1	9	553	3
14.	Fireclay	0	6	—	
15.	Grey Shales	3	3	557	0
16.	Hard, white Sandrock	30	1	587	1
17.	Galliard	3	4	590	5
18.	Grey Rag	4	0	594	5
19.	Sandrock	14	11	609	4
20.	Dark Shales, with nodular Ironstone bands	31	8	641	0
21.	Hard Sandrock, with Grey Rag below	63	0	704	0
22.	Dark Shale	10	6	714	6
23.	Hard, grey, quartzitic Sandrock ..	14	0	728	6
24.	Grey Rag and Shales	19	6	748	0
25.	Sandrock	46	2	794	2
26.	Grey Rag	35	10	830	0
27.	Dark Shale	4	0	834	0
28	Grey Rag	9	0	843	0

Boring operations ceased here on February 27th, 1903, at the base of the grey rag, with dark shales beginning to appear. With pipes down to 282 feet, and pumping at the rate of 8,000 gallons an hour, the water was exhausted in five hours, but rose again in the well at the rate of 12 inches in ten minutes, when operations ceased.

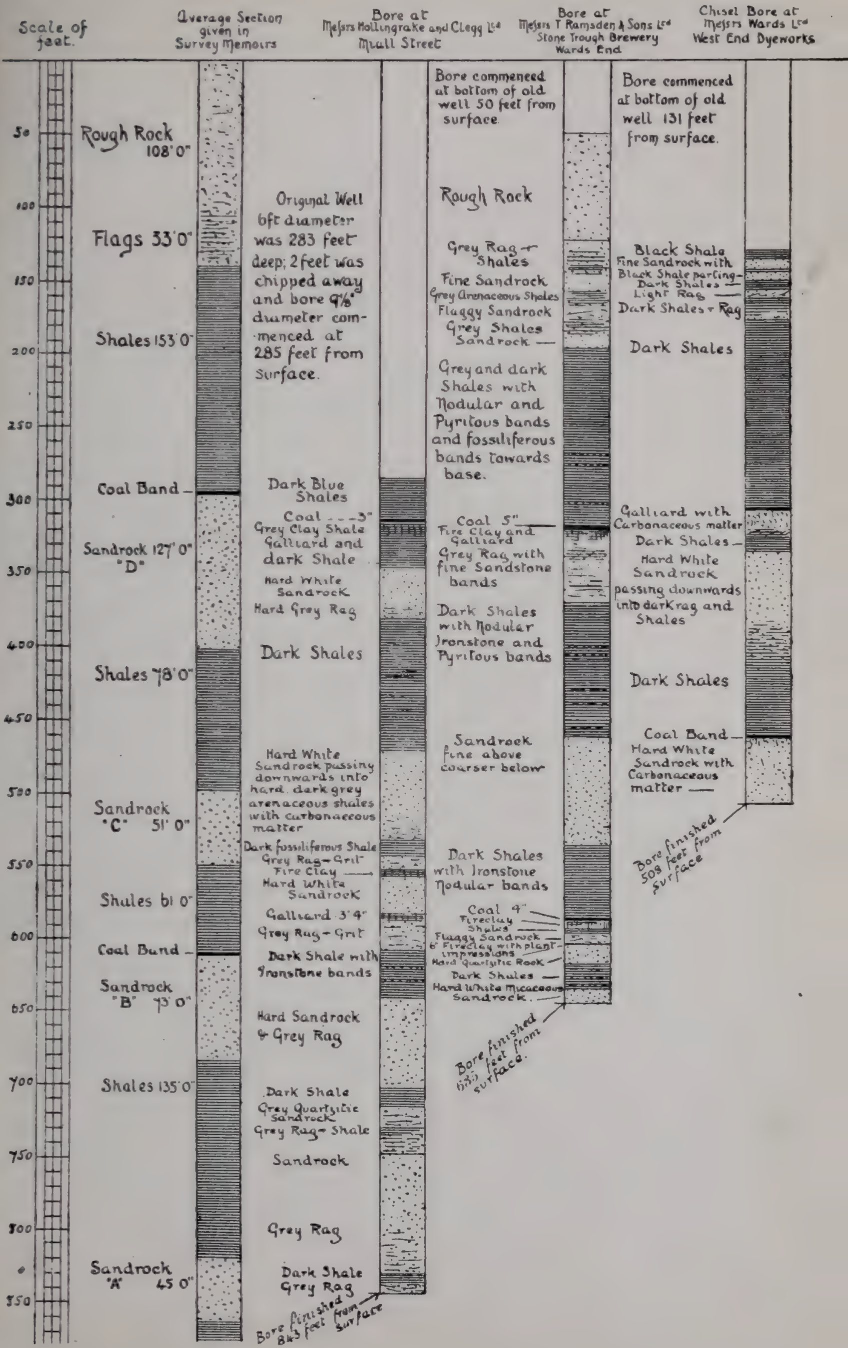
Taking into consideration the fact that this bore is 200 feet higher up the dip slope than Messrs. Ramsden's, it would appear that a permanent supply could only be obtained by sinking the pump pipe to a considerably lower level.

In comparing and endeavouring to correlate the strata of the bores with the Survey section, there is at the outset one good horizon that is clearly definable: that is the coal band at the top of what are known as the Third Grit series, which comprise the four beds of Sandrock, D, C, B, A, and their associated shales.

Although in Messrs. Ward's section this coal was not specifically recorded, I think we may safely assume its presence as a thin band. It must be remembered that this bore was made by a jigging chisel, which would break a soft band of coal into fragments very quickly, and mix them with the rock below. This rock (numbered 12 in my record of the boring), though broken up very finely, was almost certainly a Galliard, and came up mixed with a considerable quantity of carbonaceous material.

Sandrocks D and C and the intervening shales appear fairly clear also; although D has obviously thinned out and given place to shales, whilst the coal band at 463 feet in Messrs. Ward's section is not seen in the others. Below C, correlation is more difficult and any conclusions may be open to doubt; although it will be noted that the coal at the top of Sandrock B is traceable by an almost parallel band in Messrs. Ramsden's bore, and by the Galliard or Fireclay in that of Messrs. Clegg. I feel some justification, therefore, in holding the opinion that Messrs. Ramsden's operations ceased in Sandrock B, and Messrs. Clegg's at the base of Sandrock A.

There was some discussion and question in connection with these borings, as to the probability of a good water supply


Scale of feet.
Average Section given in Survey Memoirs
Bore at Messrs Hollingrake and Clegg Ltd Mull Street
Bore at Messrs T Ramsden & Sons Ltd Stone Trough Brewery Wards End
Chisel Bore at Messrs Wards Ltd West End Dyeworks
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
Rough Rock 108' 0"
Flags 33' 0"
Shales 153' 0"
Coal Band
Sandrock 127' 0" "D"
Shales 78' 0"
Sandrock "C" 51' 0"
Shales 61' 0"
Coal Band
Sandrock "B" 73' 0"
Shales 135' 0"
Sandrock "A" 45' 0"
Original Well 6ft diameter was 283 feet deep; 2 feet was chipped away and bore 9⅛" diameter commenced at 285 feet from surface.
Dark Blue Shales
Coal - - - 3"
Grey Clay Shale
Galliard and dark Shale
Hard White Sandrock
Hard Grey Rag
Dark Shales
Hard White Sandrock passing downwards into hard dark grey arenaceous shales with carbonaceous matter
Dark fossiliferous Shale
Grey Rag & Grit
Fire Clay
Hard White Sandrock
Galliard 3' 4"
Grey Rag & Grit
Dark Shale with Ironstone bands
Hard Sandrock & Grey Rag
Dark Shale
Grey Quartzitic Sandrock
Grey Rag & Shale
Sandrock
Grey Rag
Dark Shale
Grey Rag
Bore finished 843 feet from surface
Bore commenced at bottom of old well 50 feet from surface.
Rough Rock
Grey Rag & Shales
Fine Sandrock
Grey Arenaceous Shales
Flaggy Sandrock
Grey Shales
Sandrock
Grey and dark Shales with Nodular and Pyritous bands and fossiliferous bands towards base.
Coal 5"
Fire Clay and Galliard
Grey Rag with fine Sandstone bands
Dark Shales with Nodular Ironstone and Pyritous bands
Sandrock fine above coarser below
Dark Shales with Ironstone Nodular bands
Coal 4"
Fireclay
Shales
Flaggy Sandrock
6" Fireclay with plant impressions
Hard Quartzitic Rock
Dark Shales
Hard White Micaceous Sandrock.
Bore finished 635 feet from surface.
Bore commenced at bottom of old well 131 feet from surface.
Black Shale
Fine Sandrock with Black Shale parting
Dark Shales
Light Rag
Dark Shales & Rag
Dark Shales
Galliard with Carbonaceous matter
Dark Shales
Hard White Sandrock passing downwards into dark Rag and Shales
Dark Shales
Coal Band
Hard White Sandrock with Carbonaceous matter
Bore finished 508 feet from surface

being obtained if the bore were carried down into the massive Kinderscout Grits at the base of the Grit series.

It is of course difficult to say, and unwise to be dogmatic in any statement of opinion, but I am inclined to think that a good supply would not be obtained, and still less that any such supply would repay the heavy expense of a bore so deep. If the Grits of this dip slope are as consistent with the Survey averages throughout their whole depth as these borings appear to me to indicate, it would be necessary to go down 1,300 feet to tap the possible water supply of the Kinderscout Grits.

The outcropping area of the Kinderscout Grits north of the Calder is on the flanks of Hebden Valley and Crimsworth Dean, and on the moorlands to the west of these valleys. Much of the water gathered by the rocks to the west must be caught by these two valleys, which largely intersect the beds and cut down to the Pendleside series below. There is only a small surface outcrop on the easterly valley sides and hill slopes, too small in my opinion to give a gathering ground likely to furnish any considerable quantity of water. Neither does it appear likely that much water can get through from the beds which successively overlie the Kinderscout Grit, if the shales which part it from the next Sandrock above maintain anything like the thickness shown in the Survey section.

I would express my thanks and indebtedness to the principals of the three firms for their uniform courtesy in allowing me access to their premises and operations at all times, and also to the operative engineers engaged in carrying out the work, for leave to inspect and compare their records with my notes, and particularly for their kindness in keeping me samples of every change in the character of the rock, without which, in the case of the chisel bore, careful records would have been almost impossible.

My thanks are also due to Mr. J. H. Howarth for help and advice in noting Messrs. Ramsden's boring.

LAND-SHELLS IN THE INFRA-GLACIAL CHALK-RUBBLE AT SEWERBY, NEAR BRIDLINGTON QUAY.

BY G. W. LAMPLUGH, F.G.S.

In the coast-sections around Flamborough Head the Glacial deposits are frequently underlain by an earthy chalk-rubble of variable thickness, to which the term "chalk-wash" was applied by Mr. J. R. Dakyns.* This chalk-rubble usually rests directly upon the chalk, but at the crest of the buried rock-cliff beneath the drifts at Sewerby near Bridlington Quay, the rubble passes off the chalk and covers the fossiliferous "Infra-Glacial" beds which have been preserved under the lee of this old cliff, as shown in the accompanying section (Fig., p. 94).† By previous researches it has been proved that the chalk-rubble to the westward of the old cliff not only descends rapidly to sea-level but sinks still lower as we approach Bridlington Quay, so that, near Sands Cut, its top, as proved by borings through the Basement boulder-clay, lies 22 feet below the level of the shore.‡

Though it has long been recognised that this chalk-rubble probably represents the sub-aerial waste of an old land surface,§ the material had not hitherto yielded any fossils except a single limb-bone of *Bos* or *Bison*.|| While living in the neighbourhood I searched it repeatedly without success; but during a recent visit to Bridlington, in examining a good exposure of the bed on the foreshore between 200 and 300 yards S.W. of the Sewerby buried cliff, I noticed some thin seams of brown loamy earth intercalated with the fine chalk-rubble, and found that small

* Proc. Yorks. Geol. and Polytec. Soc., vol. vii., pp. 249-252.

† "Report on the Buried Cliff at Sewerby," Proc. Yorks. Geol. and Polytec. Soc., vol. ix. (1887), pp. 382-392; and Rep. Brit. Assoc. for 1888.

‡ Proc. Yorks. Geol. and Polytec. Soc., vol. xi. (1889), p. 284.

§ J. R. Dakyns, op. cit., and G. W. Lamplugh, Quart. Journ. Geol. Soc., vol. xlvii., p. 414.

|| See "Drifts of Flamborough Head," Quart. Journ. Geol. Soc., vol. xlvii., p. 394.

land-shells occurred plentifully in this earth. The chalk-rubble on the foreshore in which these shells were found was about 30 yards from the base of the present cliff, and extended in a strip from three to five yards wide for about 150 yards, disappearing southward beneath boulder-clay which was exposed for about 50 yards further. I had not before seen so good an exposure on this part of the shore.

In the cliff just opposite the middle portion of the exposure, the chalk-rubble is well seen in section, having a thickness there of ten feet. In this section it is immediately covered by boulder-clay, the junction-plane being sharp and definite. After finding the shells in the shore-exposure I was able to detect them also in an earthy seam in the rubble near the base of this cliff (Fig., p. 94).

The shells are in a very fragile state, and at present only one species has been recognised :—*Pupa muscorum*.* But a small *Helix* is probably also present, though not identifiable in the material submitted to palæontological examination at the Museum of the Geological Survey.

Samples of the shelly earth were washed and sifted in the hope that it might yield other organic remains; but with the exception of one small carbonaceous fragment, which may have been of vegetable origin, no other fossils were found.

The chalk-rubble is almost wholly composed of small angular fragments of chalk ranging from one-eighth to half an inch in diameter, firmly set in a matrix of yellow silty clay which may represent the residue from decomposed chalk. Occasionally there are seams of larger fragments of chalk, up to one to two inches in diameter, but these are comparatively rare, and it is singular how comparatively regular and even has been the trituration of the hard rock which has gone to form the bed. The chalk-rubble appears to be unlike any superficial deposit which is at present being accumulated from the waste of chalk surfaces, and it probably represents the weathering of the chalk slopes under peculiar climatal conditions which

* I am indebted to Mr. E. T. Newton, F.R.S., for this determination.

prevailed immediately before the invasion of the district by the ice-sheet.

Besides chalk fragments, however, the bed contains a fair sprinkling of small chips of grey flint and of well-rounded grains of quartz-sand. Close search also reveals the presence of a few small fragments of hard grey grit or quartzite and of other stones foreign to the district, including a greenish basaltic rock, though these are very rare. The occurrence of the flint chips is remarkable, as the chalk which forms the neighbouring slopes contains no flint, and the nearest outcrop of the flinty Middle Chalk, from which the fragments appear to have been derived, lies over two miles distant to the northward, and is separated from these slopes by the wide pre-Glacial depression of the Bempton Valley.

Another significant fact is that although the bed at this place is made up almost exclusively of fine detritus, I noticed in the cliff-section during a previous visit to the locality (in November, 1902) an angular block of hard yellowish-white sandstone or grit, measuring 1½ feet by 1½ feet by 1 foot, embedded at the base of the rubble just above the blown sand of the Buried-Cliff Beds. This boulder is probably from the same source as the small fragments of grit mentioned above. It is the only large boulder which I have seen in the chalk-rubble at Sewerby, though many years ago I found a boulder of quartzite 21 inches in diameter in the chalk-wash which underlies the drift at Danes' Dyke, 1½ miles farther eastward.* It is noteworthy that a few erratic stones, chiefly of sandstone and basalt, were obtained in excavating the old beach-deposit at the foot of the Sewerby buried cliff; and that in the land-wash which rested on this old beach and was covered by blown sand, we found four species of small land-shells, including the species which has now been found in the chalk-rubble.†

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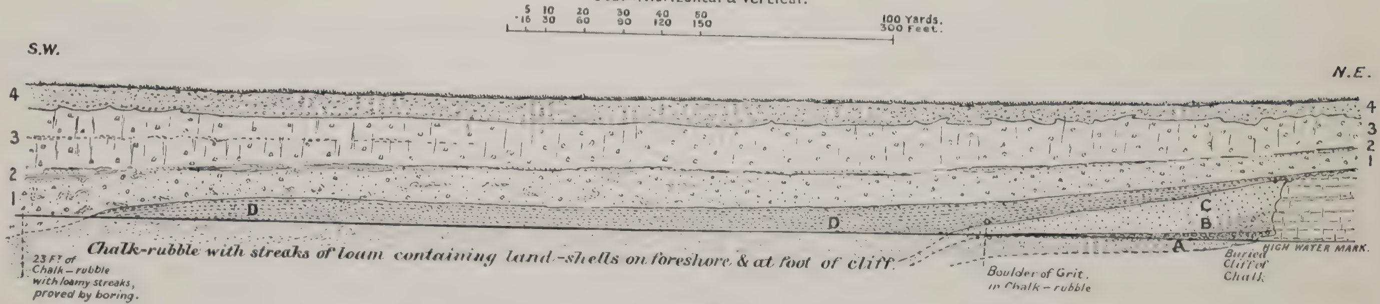
* "Drifts of Flamborough Head," Quart. Journ. Geol. Soc., vol. xlvii., p. 397.

† Reports on the Buried Cliff, op. cit.

Cliff-Section at Sewerby, near Bridlington Quay.

The Buried Cliff of Chalk runs in obliquely behind the line of section & the covering beds slope away from it towards the spectator.



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Glacial Drifts.

4 — The Sewerby gravels (late glacial.)
3 — "Purple" Boulder-clay splitting into two bands, South-Westward, with stratified material intervening.
2 — Stratified clay, loam, sand & gravel, nearly thinning out North-Eastward.
1 — "Basement" Boulder-clay including contorted patches of loam, chalk-rubble, etc. towards base.

Infra-Glacial Beds.

D — Chalk-rubble. (see text)
C — Blown Sand, with bones, etc, (a land-shell found in a loamy band near top.)
B — Land-wash banked against the buried cliff, with bones & numerous land-shells.
A — Old Sea-beach, with bones & marine shells.

One point of consequence in the occurrence of the land-shells now found in the chalk-rubble is that their position on the shore is several feet below the level of the ancient beach, and furthermore that the bed in which they are enveloped is known to descend at least 25 feet lower than this level,* and is probably prolonged to a still greater depth. We thus obtain definite proof that an elevatory movement, already postulated on less direct evidence,† has followed the stage of slight depression marked by the Sewerby Buried Cliff.

Another point of great interest is the close correspondence which can be now established between the Infra- (or pre-) Glacial beaches of South Wales, as described by Mr. R. H. Tiddeman‡; of County Cork, recently discovered by Messrs. Muff and Wright§; and of East Yorkshire. In each case the old beach is covered by blown sand, and then by a wash of local rubble or "head," and the whole series hidden under boulder-clay; and in each case there is proof of some degree of elevation before the invasion of the country by ice.

The presence of the flints and of occasional extraneous fragments, and especially of the grit boulder, in the chalk-rubble, together with the extraordinary poverty of the fauna (if, indeed, this be not merely an accident of preservation), point to the likelihood that the ice-margin was already not far distant from the neighbourhood when the bed was being formed. We have still much to learn about the succession of events during the early stages of the Glacial Period in England; and therefore every little glimmering fact that may aid in dispelling the obscurity has its value.

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* Proc. Yorks. Geol. and Polytec. Soc., vol. xi., p. 284.

† "Drifts of Flamborough Head," op. cit., p. 416.

‡ Rep. Brit. Assoc. for 1900 (Bradford), pp. 760-762.

§ Rep. Brit. Assoc. for 1903 (Southport).

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(1839-1902),

BY

W. LOWER CARTER, M.A., F.G.S.,

Honorary Secretary.

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NOTES FOR THE FIELD EXCURSION TO MELROSE.

July 10th to 15th, 1902.

BY B. N. PEACH, F.G.S., OF THE GEOLOGICAL SURVEY OF SCOTLAND.

Melrose makes a good centre near the Borders for studying peculiar igneous rocks which could give off recognisable boulders.

I. The volcanic platform of the "Kelso Traps" of Lower Carboniferous age can be studied by taking train to Rutherford Station, where the Tweed makes a slight gorge through them (see published Geol. Sur. one inch map 25 and Fig. 2 opposite), and their relations to the underlying Upper Old Red Sandstones and the overlying "Tuedians," or Cement Stone Group of Scotland, can be seen. On the west side the traps are faulted against the Upper Old Red Sandstone, and on the east side they pass upwards into the overlying Cement Stone Group (the "Tuedians"). The rocks of this platform are mainly olivine dolerites ("Jedburgh Type" of Sir A. Geikie). A big intrusive sheet of dolerite that caps the Penel Heugh, three miles to the south of Rutherford, might be visited on the same day. Sheets and cappings of the same type of rock occur at Dryburgh, a little to the north of the Abbey, and capping the Red-path Hills, 2½ miles north of Dryburgh and four miles east of Melrose.

II. A peculiar and remarkable set of igneous intrusions occurs round Melrose and near Earlston, intrusive in the Silurian and Upper Old Red Sandstone rocks. Sections 1 and 2 show the relations of these igneous rocks in the Eildon Hills to the Silurian and Upper Old Red Sandstone strata. As shown on the one inch map, the pipes which supply the capping sheet are well seen on the west side of the Mid Eildon. One is very well seen in the quarry between the Mid and East Eildon, where it rises through the Upper Old Red marls and spreads over them, altering and discolouring them. At its northern margin spherulitic structure is well seen, the spherules sometimes being

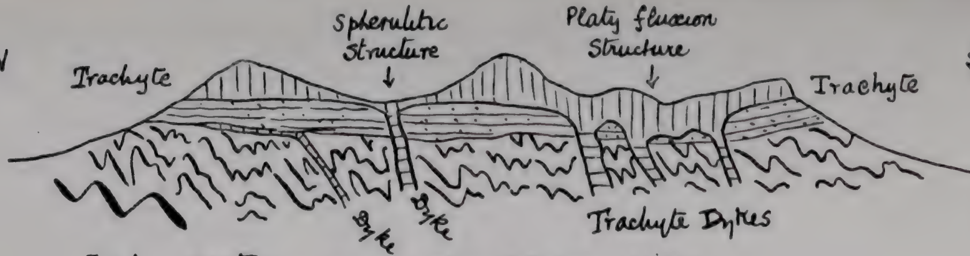

Fig. 1. Section across the Eildon Hills.

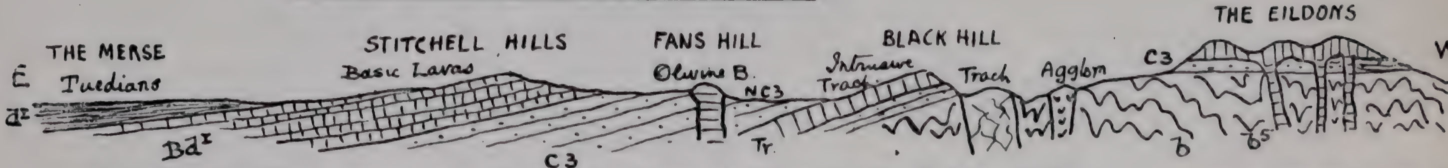

Fig. 2. Section across the Merse of Berwickshire to the Eildon Hills.

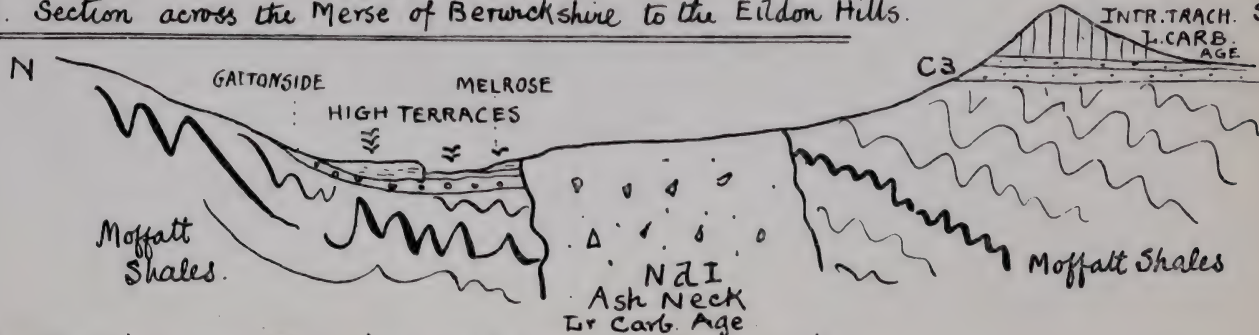

Fig. 3. Section across Gattonside and Melrose to the Mid Eildon.

arranged in the long chain-like rods. The rocks are varieties of trachyte. Those of the Mid Eildon contain riebeckite. A platy structure is very conspicuous in some of the pipes and masses between the Mid and the Western Hill. This is due to the felspars being oriented in the direction of the flow of the material. A detailed description of the petrographical characters of these rocks is given by Mr. T. Barrow, now of the Geol. Sur. of Egypt, in the Geol. Mag. for 1896, page 371. He was the first to detect riebeckite, nepheline, and ægerine in them. He came to the conclusion that the rocks capping the Eildons are remnants of lava flows once continuous with those of the Black Hills of Earlston. With this conclusion I do not agree. The sheets are transgressive across the underlying Old Red strata. A similar sheet is found at a lower level in the Upper Old Red Sandstone on the East Eildon, which not only is transgressive from the Silurian rocks into the Upper Old Red, but alters the strata above it as well as below.

A small outlier from the Eildon sheets is found in a quarry on the side of the Bowden Road, three-quarters of a mile to the west of the Eildons.

Large vertical dykes of the platy fluxion trachytic rocks are found on Coldshiels Hill, $2\frac{1}{2}$ miles south-west of Melrose.

A very fine example of trachyte or rhyolite dyke, showing spherulitic structure and beaded fluxion structure, is well seen near the head of the Rhymers Glen, where it is intruded into the Silurian rocks close to the outcrop of the Moffat Graptolitic black shales. This glen also gives a very good section through the great "ash neck," also of Lower Carboniferous age. (See Fig. 3.) The walk through the Rhymers was a favourite one of Sir Walter Scott's.

Eastward from Melrose there are several intrusions of this acid type. The chief, however, is that of the Black Hill of Earlston, three miles E.N.E. of Melrose. The rocks here are described in Mr. Barrow's paper already referred to. The rock is a sanidine trachyte. This rock is plainly intrusive. It can be seen in the quarry which yields the good specimens of *Holoptychius nobilissimus*, where it cuts across the overlying strata and alters them.

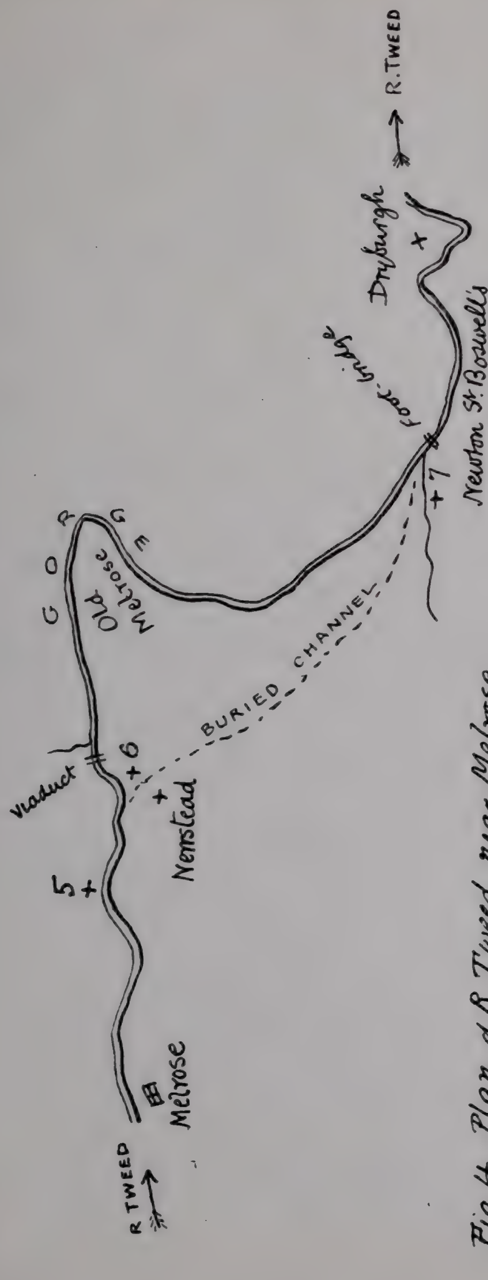

Fig. 4. Plan of R. Tweed, near Melrose

5. Cowies Hole   6 Bend of Tweed below Newstead & above viaduct

7. Foot of St. Boswell's Burn below Newton St. Boswell's, and just above the foot-bridge leading to Dryburgh. (See sections 5, 6, and 7.)

Other measures, partly intrusive in Silurian and partly in the Upper Old Red Sandstone, occur, one near Earlston and the other in the Tweed at the great bend at Old Melrose.

At Melrose high-level alluvial terraces are very conspicuous. A fine example of buried river gravels below boulder clay is seen at Cowies Hole, about one mile below Melrose, at Newstead, and again at Newton St. Boswells, the rock gorge of Old Melrose being clearly post-glacial.

III. Ash necks of Lower Carboniferous age are common in the region. A very large one occurs at Melrose, and most of the houses in Melrose are built of the agglomerate from the Quarry Hill near Melrose railway station.

A small ash neck is found at the right bank of the Tweed opposite Dryburgh.

Another is found to the east of Coldshiels Loch, about three miles west of Melrose, and another occurs near Selkirk.

Several of these necks occur near Hassendeen Station, south of Melrose. Minto Craigs is another, and Rubers Law is a very conspicuous one to the east of the Minto.

IV. Take train to Gordon or Greenland Station on the Berwickshire railway. Some masses of intrusive porphyrite of Lower Old Red age, and which are represented as pebbles in the Upper Old Red, make up the Dirrington Laws (N. edge of sheet 25), also a hill entirely surrounded by Upper Old Red Sandstone west of Polwarth. These would afford conspicuous boulders.

V. Proceeding by same railway as far east as Dunse the granite of Cockburn Law could be visited, and fine sections of the Calciferous Sandstone. The Upper Old Red Sandstone and Silurian rock could be seen, as well as the dolerite mass of Dunse Law (sheet 33).

VI. Train to Stobs Station, S. of Hawick. Here we find a set of necklike masses of trachytic rocks, Pencline Pen, Skelfhill Pen, and several masses to the south-west. These are very conspicuous rocks, like the fluxion trachytes of the Eildons and Coldshiels Hill.

VII. Train to Shankend Station, south of Hawick. Above Shankend Shiels, three miles S.S.E. of station, a peculiar bed

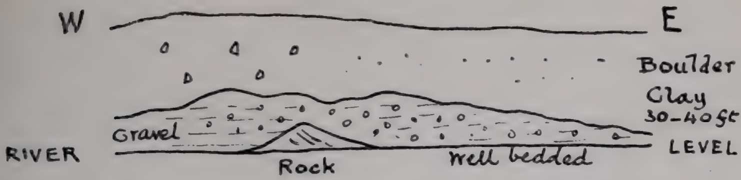

Fig. 5. Section at Corrie's Hole about 1 mile below Melrose.

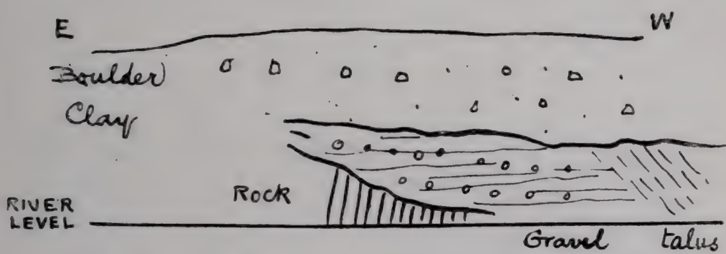

Fig. 6. Section at the 'Bullers' below Newstead. About 1½ miles below Melrose.

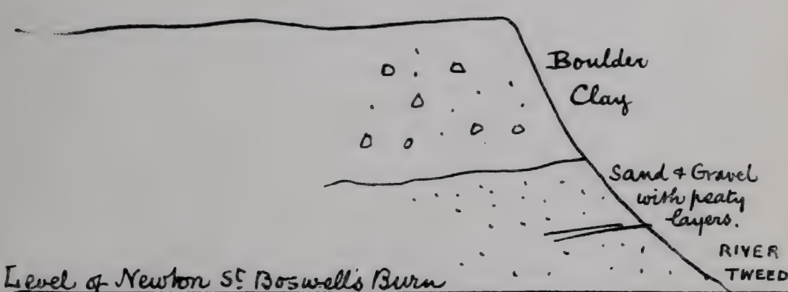

Fig. 7. Section seen at junction of Newton St Boswell's Burn with River Tweed, 3 miles E.S.E. of Melrose, and a little above the Suspension Foot-bridge from St. Boswell's to Dryburgh.

of pink chert or carnelian occurs on the horizon of the Cornstone at the top of the Upper Old Red, just underlying a series of basic lavas on the horizon of the "Kelso Traps." The Cornstone itself, which is associated with the chert, should be studied, as it is a conspicuous band which occurs intermittently from this point to Carham-on-Tweed to the east, and also very much further to the west as far as Kirkcudbrightshire. There is a peculiar ash associated with the lavas in this region. It is full of little pellets of hæmatite or limonite. In this region the necks of the Maiden Paps or Greatmoor could prehaps be visited during the one excursion.

Note about the Eildon and Black Hill Trachytes.

It should be remembered while studying these rocks that almost all over the south and west of Scotland the earliest lava flows are very basic, such as olivine basalts, limburgites, etc. These occur just at the top of the Upper Old Red beds or at the very base of the Carboniferous. They are generally succeeded by andesitic basalts and andesites, and in several places, such as the Garleton Hills, the Campsie Fells, and the Renfrewshire Hills, the latest rocks reach the stage of trachytes, phonolites, and nepheline-bearing rocks.

The Kelso traps, as can be seen, are all very basic, and their horizon is distinctly marked. The Eildons and the other intrusions evidently belong to the latest phases of the Lower Carboniferous volcanoes. Plenty of evidence on this point is afforded by the fragments of cement-stone and limestone that have fallen back into the numerous necks that are associated with their trachytic rocks.

VIII. Arenig jaspers and cherts associated with the Lower Silurian rocks, haggis rocks, and greywackes of the Southern Uplands.

Take train up Gala Water to Heriot Station. Cross to west side of them. Walk back one mile down Gala Water to past the mouth of Heriot Water and Cashope Burn. In the corner of a field west of road on southern outcrop of black shale, shown on map 25, see outcrop of jasper associated with grey and black chert; some dykes of felsite or porphyrite to south; near Fontanhall Station several outcrops of pebbly greywackes.

Observe the great trains of greywacke débris on hill slopes between Galashiels and Stow.

Buckholm Hill, near Galashiels, gives splendid examples of Queensbury grits.

IX. Observe the peculiar stained greywacke pebbles making up the Upper Old Red conglomerate in Leader Water above Earlston. How like boulder-clay stones. See junction of conglomerate and greywackes opposite to Caroside. The underlying rocks look like *roches moutonnées*.

Observe the remains of staining of the greywackes on the Gattonside side of Melrose.

SECRETARY'S REPORT, 1902.

It is my pleasant duty to report another year of prosperity and useful work.

In connection with the Spring Council Meeting a visit was arranged to the Leeds Museum, on Thursday, February 27th, to witness an experiment made by the Leeds Association of Teachers for interesting the scholars of the Leeds schools in the Museum. A lecture was given to 400 children of the elementary schools, by Mr. Henry Crowther, F.R.M.S., the Curator, and a tour round the Museum was arranged to illustrate and enforce the lecture.

A General Meeting was held the same evening in the Leeds Church Institute (Chemist's Room), by the kind permission of the Leeds Chemists' Association, under the presidency of Mr. F. W. Branson, F.I.C., in place of Dr. D. Forsyth, prevented from being present by illness, at which a paper was read by Mr. A. R. Dwerryhouse, B.Sc., F.G.S., on "The Glaciation of Teesdale, Weardale, and the Tyne Valley, and their Tributary Valleys," which was illustrated by photographs and lantern diagrams. The paper described a very interesting and important addition to our knowledge of the Glacial history of North-east England, the complete account of which has been published by the Geological Society of London. After an interesting discussion the Hon. Secretary read a paper by Mr. J. R. Dakyns, M.A., on "Notes on the Geological Phenomena of part of Wharfedale, near Grassington, from MS. written in 1878." This paper was followed by a discussion in which Messrs. Kendall, Howarth, and others took part, and the proceedings were concluded by a warm vote of thanks to the Chairman.

The spring excursion was commenced under the most favourable conditions of weather. The contingents from various parts of the country met at Goathland on Friday, April 25th, and proceeded to view some gravel deposits, which are supposed to be the remnants of an old lake beach, under the guidance of Mr. P. F. Kendall, F.G.S., the leader of the excursion.

The main object of the meeting, as explained by the leader, was to study in the field the evidence which shows that an ice-sheet surrounded the Cleveland Hills in the Ice Age, on the north, east, and west, which impounded the natural drainage of the interior ice-free region, so as to form a series of lakes. At the period of maximum extension the great ice-sheet, advancing on the Cleveland area from the north and north-east, abutted against the outer margin of the hills at elevations from 1,000 feet near Stokesley to 600 feet near Scarborough. The interior of the Cleveland area at this time did not support any native glaciers. The Vale of Pickering became a lake at an early stage of the Glacial Period, the outlet to the sea at Filey being closed. Newton Dale was then the overflow trench of the northern impounded waters, and a great delta of large cobbles, including specimens of the Cleveland dyke and other North Yorkshire rocks, was thrown down at its southern end; but at a subsequent date, when a channel gave egress to the northern waters by way of Scarborough, this fine gorge (Newton Dale) was left vacant.

After a short halt at Goathland Church, the party were reinforced by several members who had travelled from Whitby, and, 19 strong, started for Mallyan Spout, a pretty little fall into the gorge of Wheeldale Beck. Following this gorge, which has been cut since the close of the Glacial Period, as far as the moor top, a notch was discovered called Moss Slack, which is considered to mark the extreme limit of the encroachment of the Scandinavian ice in this part of Cleveland. Ascending the opposite slope to Hazel Head, the party reached a shallow channel which marks the edge of the ice-sheet, the outfall of which is just at the level of the intake of Moss Slack, on the opposite side of the valley.

Passing down the hillside from Park Rigg, Purse Moor Slack was entered, the higher of the two channels from Eskdale Lake. Randay Mere is the lower channel, a fine valley now utilised for the reservoir of the Whitby waterworks. On the moor side above is another notch, which is the deserted oxbow of the ice-front stream. The spectacle of this oxbow, the intake of which is 50 feet above the floor of Moss Swang, the upper part of Randay Mere, is very striking. The entrance to Moss Swang is about 400 feet above the floor of Eskdale.

The party returned by road to Grosmont Station, and dined together at the Crown Hotel.

After dinner the General Meeting was held under the presidency of Mr. Wm. Whitaker, B.A., F.R.S., F.G.S.

The Chairman spoke of the interest which Professor Kendall's Cleveland work had aroused in London, and the great value to geological science of his results.

Mr. P. F. Kendall, F.G.S., then read Part I. of his paper on "The Glacier Lake System of the Cleveland Hills." He said he commenced his investigations by an effort to explain the gorge of the Nidd. He was urged by Professor W. M. Davis (Harvard) to study the dry gorges, and the history of the Glacial Period would come out of them. Following up this advice he studied the peculiar character of the Yorkshire rivers. He found there were three distinct ice-streams to consider: one from the Solway along the Vale of Eden, and over Stainmoor, which could be traced step by step by its erratics all down Teesdale, the Yorkshire coast, and East Lincolnshire. Secondly, a great glacier flowing along the Tweed valley, round the Cheviots, and into Northumberland, but the definite train of its erratics is lost south of the Tyne. Then there was the Scandinavian ice, the boulders of which are found as far south as Norfolk. Mr. Kendall detailed the evidence on which he based his conclusions. His remarks were illustrated by an elaborate series of coloured contour maps, which had entailed a tremendous amount of labour, and served to make his explanations admirably clear. This interesting paper was followed by a discussion, in which the Rev. J. Hawell, Mr. J. E. Wilson, the Chairman, the Rev. W. L. Carter, and Mr. Sewell took part.

On Saturday morning the party paid a visit to the Museum at Whitby, and then took the 10.5 train to Danby. On leaving the train a visit was paid to the tile works. where the laminated muds formed on the floor of the ancient lake were examined. The northern slope of Eskdale was then mounted, and Ewe Crag Beck ascended. This, Mr. Kendall explained, was the overflow channel into Eskdale Lake of some lake lying to the north. and held up by the ice-front against the northern slope of the moorlands. The deltas of this glacial stream are clearly to be seen in two marked terraces above Dale End. These correspond in height to the two channels of Moss Swang on the southern side of Eskdale, seen the previous day, and mark the height of the lake at two periods in the retreat of the ice.

As the actual level of the rock channel is of consequence to the theories of origin, no fewer than fifty-four bore holes have been made by Mr. Kendall in the peat to test its depth, with the result that the rock channel is found exactly at the height which corresponds with other related channels.

From the northern end of Ewe Crag Slack the party crossed Danby Low Moor, knee-deep in heather, to Little Dinnond, whence a return to civilisation was made by way of the Nan Stone to Hardale Head, and Hardale Slack, another overflow glacial valley, was descended to Lealholm station, where the train was taken to Whitby.

After dinner the General Meeting was resumed under the presidency of Mr. W. Whitaker, F.R.S. Mr. P. F. Kendall, F.G.S., continued his description of the glacier lake systems of Cleveland, directing his attention to the area between Whitby and Scarborough. The ice, he said, invaded Iburndale almost to its very head, and there is a low channel, almost at the head, through which the drainage of the Iburndale Lake was discharged into Robin Hood's Bay. When the ice filled Robin Hood's Bay, it turned these drainage waters southwards, and a great intercepting drain was formed (Jugger Howe Beck). There were many oscillations of the ice-front, and oxbows were formed at several points, both on the iceward and opposite sides of the valley. On the withdrawal of the ice, which appears to have been very rapid, no evidence was left of any drainage at a le s level than 500 feet. Between Harwood Dale Moor and Hayburn Wyke six immense rock gorges are cut through a spur of rock. five miles in length, and as this great work of erosion was accomplished during so short a distance of retreat, it gives a very striking illustration of the length of the Ice Age. Mr. Kendall alluded to the excellent work accomplished by Mr. Fox-Strangways during his survey of the district, and also to the useful observations of Mr. J. W. Stather, of Hull. The paper was then discussed and a vote of thanks passed to the reader.

Monday's excursion was directed to the examination of the moorlands between Whitby and Cloughton. The members proceeded by wagonette along the Scarborough road to Kirk Moor Gate, where they were able to view the channel by which the overflow from the Robin Hood's Bay area passed into the Foulsike Valley. Crossing Sneaton High Moor on foot, two notches were seen by which the overflow of the Iburndale Lake reached Biller Howe Dale. Thence Biller Howe Slack was traversed, which cuts across three spurs of the moorland, and marks the maximum extension of the ice-sheet in this direction. Crossing the great Foulsike Valley (Jugger Howe Beck), Brown Rigg was examined, and the interesting high-level oxbow behind it aroused much interest. The Scarborough road was then regained by way of Evan Howe Slack, another overflow from the Robin Hood's Bay lakes. Rejoining the wagonette, the party were driven to see Castle Beck, where the drainage from the Helwath area passed over into Jugger Howe Beck. The moraine bordering the Jugger Howe Valley, which marks the limit of the North Sea ice-sheet, was examined. Proceeding by way of the Falcon Inn to Ringing Keld, the party walked to Cloughton Moor Cottage, crossing on the way the intakes of four successive overflow channels of a lake held up in Thorney Beck Valley during the ice-sheet, and the return was made by wagonette to Whitby.

After dinner the Rev. E. Maule Cole, M.A., F.G.S., gave an address on the "Prehistoric Entrenchments on the Wolds," which was followed by an interesting conversation. Votes of thanks were passed to the Chairman, the readers of papers, and the leader of the excursions.

On Tuesday the party went by train to Scarborough, and drove to the racecourse, examining the moraine on Seamer Moor, which marks the maximum extension of the ice in this region. On the way to West Ayton the dry valleys which carried the drainage from the ice-front were examined. From West Ayton to Wykeham the journey was continued along the remarkable gravel terrace which fringes the Corallian hills, and is now regarded as an elongated delta laid down between the hills and the ice-margin by streams flowing from the ice-free country to the north, joined to a greater overflow, the Forge Valley, from the whole country from Iburndale southward to Hackness. At Wykeham the fragmentary terminal moraine laid down at maximum ice-extension was examined, as well as a series of channels running over the gravel terrace. The return drive was taken by way of Forge Valley, the New Cut, and a series of overflow channels at Throxenby Mere, and the members separated after passing a thoroughly hearty and unanimous vote of thanks to Mr. Kendall for the enjoyable and instructive excursion which they had been privileged to make under his leadership.

The summer General Meeting and Field Excursion were held at Melrose, under the presidency of Mr. James H. Howarth, F.G.S., for the examination of the rocks of the south-east of Scotland adjoining the English border, which might give rise to conspicuous glacial boulders. The members assembled at Melrose on Wednesday, July 9th, on the advice of Mr. B. N. Peach, of the Geological Survey of Scotland, who kindly wrote a series of notes on the igneous rocks of the district for the guidance of the party (see page 154).

Thursday, July 10th, was occupied with a visit to Jedburgh. After examining a section of Old Red Sandstone overlying Greywacke Grits near the station, the party went to Lanton Hill, where a mass of agglomerate associated with an extensive extrusion of dolerite was examined, and subsequently the dolerite boss of Dunian Hill was visited. The latter is worked for road metal and shows an imperfect columnar structure, and where weathered took on a concretionary form. On the return journey a visit was paid to the fine old Abbey of Jedburgh.

On Friday an early visit was paid, under the leadership of Mr. Percy F. Kendall, F.G.S., to the quarry in the Melrose volcanic neck, which is a great mass of agglomerate, about a mile square, filling up the old vent of the volcano. The party then took train as far as Tynehead, in the Lammermuirs, where a fine section of drift was examined for rocks from the Highlands, but a few doubtful specimens were all that were found. Between Tynehead and Heriot a long glacial overflow valley was examined, which crosses the watershed into the Forth valley and must have carried a large volume of water. The course of Gala Water was followed from Heriot to Fontanhall. Graptolitic shales were searched for fossils, but without success, but in an adjoining boss radiolarian cherts are found associated with jasper rocks.

The General Meeting was held at the King's Arms Hotel, Melrose, when three new members were elected, and an interesting account of the ancient volcanoes of Southern Scotland was given by the Rev. W. Lower Carter, M.A., F.G.S. The writer, in briefly reviewing the ancient volcanic phenomena of Great Britain, showed that in Ordovician times there were great eruptions in North Wales, forming first a great volcano in Merioneth, of which Cader Idris is a relic, and subsequently one of equal size in Carnarvonshire. The chief vent of the latter was in the neighbourhood of Aber, and the mountain masses of Carnedd Dafydd, The Glwydrs, and Snowdon were composed of parts of its huge cone. In the Lake District there were in this period also great eruptions extending over a large area, and another centre of vulcanicity was the south-eastern corner of Ireland. In Southern Scotland there were also great volcanic outbursts in Ordovician times, but the vents were so covered up by lava sheets that it was difficult to identify them. In Old Red Sandstone times there were vigorous eruptions along the margins of the great lakes which occupied immense stretches of mid and northern Scotland. So vast were the discharges that the remains now form ranges of hills, stretching from 40 to 50 miles, and rising 2,000 feet above sea-level. These were followed in Lower Carboniferous times by great outpourings of lava, which formed plateaux extending from Stirling to Arran. After these plateaux eruptions there came a fuller phase of volcanism, in which the central valley of Scotland was the centre of activity, large numbers of puys, or small volcanoes, being formed. Permian and Tertiary times also added to the long list of vigorous volcanic outbursts in southern Scotland, but the Secondary period seems to have been entirely quiescent. The paper was followed by a discussion, and the writer was heartily thanked for his services.

The General Meeting was continued on Saturday evening, when Mr. Percy F. Kendall, F.G.S., delivered an address on "The Glacial Problems of the Tweed Valley." He pointed out that we find evidences in the Glacial Period of the interference all along the east coast by the Scandinavian ice sheet, deflecting the British ice either northwards or southwards. In Caithness the ice was deflected to the north across the land and round to the north-west. In the Firth of Forth the great mass of the Highland ice was forced over the watershed westwards into the Clyde drainage area, and so helped to cause a congestion of ice in the Irish Sea, and hence contributed to the pressure of ice in the Vale of Eden, which made the overflow into Teesdale possible.

At the head of the Tweed valley the drift contained large quantities of disintegrated Trias, brought by ice from the Irish Sea basin which had overridden the watershed. This stream was driven round the corner of the Cheviots at a time when the Cheviot glaciers had become small. The Tweed valley is striated parallel to its axis, and is also ridged parallel to the same line, and the phenomena of crag and tail shown by many hills point to the same movement along the valley. When the end of the Cheviots is reached these features all swing round with Cheviot as a centre. The overflow valleys across the spurs of Cheviot prove that these valleys were obstructed by ice at their mouths at a period when they were not filled with local glaciers. In considering the Forth ice, the overflow at Heriot proves that the Tweed ice dwindled before the Forth ice, and this is confirmed by the overflow valleys and other glacial phenomena of the eastern Lammermuirs. Other evidence combines to prove that there was a progressive dwindling of the British glaciers from south to north at the close of the Glacial Period, and probably the Scandinavian ice-sheet diminished in the same direction, thus giving a fall in the ice-surface to the south. This explains the fact that the overflow valleys are found plentifully on the south slopes of the principal east and west valleys, but very seldom on their northern sides, the free drainage being southwards into a great North Sea lake, and outwards, in all probability, by the Straits of Dover, which would be a great glacial overflow.

During the excursion Fans was visited and two large masses of olivine dolerite in the neighbourhood examined. These showed beautiful columnar structure, as also did a boss of dolerite near Dryburgh. A visit was paid to Duns to examine the granite of Cockburn Law. The edges of the mass were only seen *in situ* showing a fine-grained bluish-grey granite, with occasional pinkish patches. Boulders, which were very plentiful, gave a coarser rock very rich in biotite, and forming a basic granite or granitite.

This excursion also revealed a very interesting river diversion, the Whiteadder crossing the igneous mass in a deep gorge, which must have been due to interrupted eastward drainage by ice.

The Black Hill of Earlston was ascended and the sanidine trachyte examined. In a quarry on the flank of the hill the igneous rock was seen overlying the Old Red in a beautiful section, and contact specimens were obtained. The igneous rock was beautiful, variegated along joint planes by infiltration dendritic markings. At Bremerside, near Dryburgh, a mass of platy trachyte was examined, which was probably part of the same sheet as the Black Hill. A visit was paid to the Eildon

Hills and their cappings of trachytic rock examined. This igneous sheet was intruded into the Upper Old Red Sandstone rocks, and a quarry between the Mid and East Eildon shows one of the pipes, and pieces of altered marl are found caught in the igneous mass. In Mid Eildon specimens were obtained of a variety of the same rock containing riebeckite. To the north of the Eildons is a large mass of volcanic agglomerate filling the neck of an old volcano, and forming now a mass about a square mile in area. A similar neck was examined near Jedburgh, associated with extensive extrusions of dolerite. The Tweed below Melrose exposes in its banks some interesting glacial sections, and there is an old river valley, across the corner of the bend at Old Melrose, which is choked with drift. There is a ring of high-level gravels running round the sides of the valley from St. Boswell's to Galashiels, which probably mark the edges of a lake. Opportunity was taken to visit the renowned Abbeys of Melrose and Dryburgh, and all pronounced the field excursion to have been most pleasant and instructive, and it is hoped that it will lead to the identification of some rocks in the East Yorkshire drifts which have not hitherto been located.

The Underground Waters' Committee has continued the investigation of the drainage of the slopes of Ingleborough in conjunction with the Committee appointed by the British Association. At the Belfast meeting the following report was presented to the Geological Section by Mr. A. R. Dwerryhouse, M.Sc., F.G.S. :—

On referring to the last report of the Committee for the Investigation of the Underground Waters of Ingleborough it will be seen that on September 5th, 1901, three-quarters of a pound of fluorescein was put into the water flowing down Long Churn, near Alum Pot, at four p.m., and that a further quantity of three-quarters of a pound was introduced at 5.30 p.m. on the same day. At the time of writing the last report the outflow of this had not been observed; but it has since been learned that it issued from Turn Dub, on the opposite side of the river Ribble, and close to the bank of that stream, on September

17th. The water therefore took twelve days to accomplish a journey of $1\frac{1}{2}$ miles.

The extreme slowness of the flow is partly to be accounted for by the dry weather which then prevailed; but when it is taken into consideration that the water of Long Churn plunges down a very steep fall into Alum Pot, the total depth of which is some 300 feet, the gradient of the remainder of the stream is considerably reduced.

The Secretary was informed by Mr. Wilcox, of Selside, that the fluorescein mentioned above had been seen in Footnaw's Hole prior to its appearance at Turn Dub.

The relative positions of Long Churn, Alum Pot, Footnaw's Hole, and Turn Dub, will be seen on reference to the plan (Plate XV.).

In dry weather Footnaw's Hole appears as a wide cleft in the limestone, with sloping banks of silt and sand round two sides, and precipitous limestone rocks on the other two. When the streams are in flood after heavy rain, or during the melting of snow, the water in Footnaw's Hole rises to the lip and flows over down Footnaws's Beck into the Ribble.

Turn Dub is very rarely dry, while it is only in exceptionally wet weather that water flows from Footnaw's Hole.

Thus it would appear that Footnaw's Hole is a flood outlet, and only comes into operation when the underground passage leading to Turn Dub is full and, therefore, unable to take the excess of water. As the lip of Footnaw's Hole is just below the 1,225-foot contour, and Turn Dub just below that of 1,200 feet, there cannot be a fall of more than 25 feet from the former to the latter.

Further, since in ordinary weather, when the stream is issuing from Turn Dub only, the water in Foonaw's Hole stands some 20 feet below the ground level, it will be seen that there must be a siphon-like passage below the river; and since the passage must be constantly filled with water up to the level of the overflow of Turn Dub, it will account for the very slow passage of the fluorescein over at least this part of the journey.

Since the water passes beneath the river Ribble it follows that there must be some impervious cover, because if this were not the case the water of the underground stream would find an escape at the lowest point, namely, in the bed of the river, and would not, as is the actual case, pass under that stream and rise some 10 or 12 feet above it on the opposite bank.

With a view to ascertaining the nature of this impervious cover and its thickness, it was determined to carry out a series of boring operations in the alluvial flat between Turn Dub and the river.

In the first place Turn Dub was sounded and found to be only about 18 feet in depth. Now Turn Dub is a circular pond of still water, and although a large stream of water flows out there is no disturbance of the surface, no welling up of the water apparent. This would lead one to suppose that the pool was much deeper than is actually the case. So far as could be ascertained by drawing the sounding-iron across the bottom of the pool, this consists of large boulders. This led your Committee to suspect that the cover consisted of boulder clay, and that the bottom of Turn Dub consisted of boulders, the clayey matrix having been removed by the action of the flowing water.

The boring operations were undertaken with a small set of hand-boring rods provided with an augur bit.

With this apparatus it was possible to prove that the bluish alluvial clay was underlain by a material consisting of a somewhat sandy brown clay with many large stones, and in every way similar to the boulder clay of the neighbourhood, which in some places can be seen close to the river bank.

The presence of numerous boulders prevented the boring operations being carried more than a matter of one or two inches into the boulder clay, so that it was impossible to obtain any definite evidence regarding the thickness of the bed.

Further, although boulder clay was proved to underlie the alluvium on both banks of the Ribble, it was impossible to obtain evidence of its existence in the river bed, as this consists of coarse shingle which could not be penetrated by the hand-boring apparatus.

In order to clear up this matter satisfactorily it will be necessary to engage the services of a professional well-sinker and to have one or two bore holes put down by mechanical means.

An investigation was also made of the streams tributary to, or in the neighbourhood of, Alum Pot.

A series of small springs rises from beneath the drift and peat near the wall at the north end of Whit-a-Green: these run together and form a small stream which sinks at P 34, a small pot-hole amongst long grass. Fluorescein was introduced here, and reappeared in half an hour at a small opening some hundred yards to the south of P 34: here the stream can be traced on the surface for twenty yards, when it again sinks.

The fluorescein was put into P 34 at 4 p.m., and was traced the following day at S 52; then overground to P 35, where it again sank to reappear at S 49; thence it flowed to P 36, and so underground to S 50, finally sinking at P 41.

The fluorescein sinking at P 41 did not affect any of the springs on Font Green, but was again seen in Footnaw's Hole.

This water must therefore go by a deep course, and eventually join the underground flow from Alum Pot to Turn Dub, *via* Footnaw's Hole.

Whit-a-Green Spring.—This rises on the higher slopes of Simon Fell at a height of 1,600 feet, and flows over the surface of the rocks of the Yoredale series till it reaches the underlying Carboniferous limestone at 1,250 feet, where it sinks at P 29.

A trial with fluorescein resulted in proving that this water flows out at S 55, and falls into the middle opening of Long Churn, known as Dickon Pot, P 30, where it joins the main stream occupying that channel.

The channel by which this stream flows can be traced for a considerable distance by means of a series of openings to the surface, and it was found to be possible to actually traverse the tunnel throughout almost its entire length; but the exploring party was eventually stopped by the roof coming down to the water level.

Small Spring to the North-east of last (S 53).—There is never much water in this spring, and it is quite dry in seasons of drought. It probably derives its water from the peat at its head.

The water sinks at P 28 and issues, as proved by a fluorescein test, at S 55, along with the water from P 29.

The underground junction of these two streams was afterwards traced, though it was found to be impossible to follow the whole length of the passage, the roof being too low, and there being deep pools of water lying in the bottom.

It may be mentioned in passing that as this was a short run methylene blue was tried for the test; but although only a small quantity of water was flowing at the time it was not seen at S 55, although one-fourth the quantity of fluorescein succeeded two hours later.

This, together with the failure of methylene blue to put in an appearance when used at Grey Wife Syke, as mentioned in the second report of this committee, demonstrates conclusively the superiority of fluorescein for purposes of this nature.

Long Churn Spring.—This rises on the upper slopes of the fell, and sinks on Borrin's Moor at P 42, and after a very short underground course issues at S 57, forming, however, only a very insignificant part of that spring.

The next series of experiments had for its object the discovery of the source of the bulk of the water at S 57.

On examining the upper part of Alum Pot Beck it was found that a large part of that stream sank at P 33, and fluorescein introduced here was seen at S 57 within an hour.

P 26 was the next point of experiment, and by a series of trials with fluorescein it was found that the water flowed underground along a well-marked line of joint to P 34*a*.

This line of joint is well marked both by crevices in the clints and by a line of pot holes, in some of which the water shows itself. It runs N. 18° W.

At P 34*a* the water falls into another open joint, running N. 25° E., which leads it to S 51, whence it runs over the surface to P 43, again beneath the surface to S 40, and then on to S 42 and P 37, where it again disappears.

At the time of these experiments the greater part of the water was sinking in the bed of the stream at P 37*a*, but a little was flowing on to P 37 near the old limekiln.

Fluorescein put into the stream just above P 37a came out at P 38, where it again sank and reappeared half an hour later almost simultaneously at S 43 and S 44.

It was then traced to P 39, where it again went underground to issue at Font Green Spring, S 45.

At P 40 part of this stream sinks (the whole of it in dry weather) to reappear at S 46, and part flows over the surface, the streams when reunited forming Selside Beck, which runs through the village of Selside and on into the river Ribble.

The above streams occupy a wide valley and would, with the exception of Gill Garth Beck (P 26 to P 37), all drain into Selside Beck were they not swallowed into cracks in the limestone.

There would appear to be two distinct sets of channels below Font Green—a deeper and a more superficial one.

The water flowing by the deeper channel—viz., that from Alum Pot, Long Churn, and P 41—reaches the Ribble by way of Footnaw's Hole and Turn Dub, while the shallower set issues on Font Green and joins Selside Beck.

Many of the underground stream courses are accessible, and may be followed for long distances with the aid of short ladders, and provided the explorer does not object to getting wet and doing a certain amount of crawling in the less lofty portions.

It was laid down in the two previous reports of this Committee that as a general rule the flow of underground water in limestone rocks follows the direction of the master joints, and this view has been strikingly confirmed by several of the experiments which have been carried out during the current year.

It was seen that in the open passages in the neighbourhood of Alum Pot was an opportunity for putting this theory to the practical test by following the water step by step in its underground journeyings.

With this object in view your Committee undertook to make a survey of some of the more readily accessible channels with the following results.

A plan of the series of passages communicating with Long Churn and joining that opening with Alum Pot was constructed, and this will be published in due course by the Yorkshire Geological and Polytechnic Society.

On this plan the directions of the principal lines of jointing have been marked for purposes of comparison with the direction of the caverns.

It may be confidently said that there is a general parallelism between joints and passages, but this is by no means so close as was at first expected.

To account for the want of parallelism between joints and passages it is necessary to study the evolution of one of these underground chambers.

The joints in the limestone undoubtedly give the initial direction to the underground stream; but as soon as a channel is formed sufficiently large to allow of a free flow of water, as opposed to mere soakage, a number of other forces come into play which tend to modify the direction so as to cause it to diverge somewhat from its original one of strict parallelism to the joints.

For example, the dip of the rocks causes the erosion of the channel to be more severe on one side than the other—namely, on the low or "down dip" side—and where there are cross-joints the dip may tend to produce a lateral escape along one of these so as to give rise to a zig-zag course.

Up to a certain point the erosion in these underground river channels is entirely by solution, but so soon as the external opening becomes sufficiently large to admit sand gravel and boulders excavation by means of attrition comes into play.

At this point in the history of a subterranean river zig-zags are changed into sharp windings, which in their turn impart a swing to the waters in the straight parts, thus causing a series of windings to be set up in a manner similar to that which goes on in surface streams.

As the external opening which gives access to the water increases in size, so does the amount of water flowing through the passage increase. An increase of volume means an increase of speed and a lessened tendency to winding; at the same time the passage must be widened so as to accommodate the increased volume of the stream.

The tendency at this stage is, then, to widen and straighten out the passages, and many are the deserted "oxbows," both large and small, which may be seen in the passages.

Some of these are small, and situated at a considerable height above the floor of the main passage, while others of more recent formation are approximately at the same level as the water-bearing passage, a few of them still being occupied by a portion of the stream in times of flood.

The condition of approximate stability is reached when the opening becomes sufficiently large to swallow the whole of the surface stream.

On the occasion of their last visit to the district your Committee hurriedly explored a cave which they had not previously seen, and are of opinion that it offers remarkable facilities for the further study of the development of underground water-courses, inasmuch as it exhibits tributary and deserted passages in every stage of development and decay.

In order to enable them to further prosecute the study of this most interesting question your Committee hopes that it will be granted a new lease of life, and therefore asks to be reappointed with a further grant.

The members of the Committee wish to tender their thanks to Mr. Theodore Ashley, of Leeds, mine surveyor, who, though not a member of either of the Committees, has given much time and care to the investigation.

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

(By permission of the British Association.)

Our Proceedings as usual have been forwarded to leading Scientific Societies in various parts of the world, and publications in exchange have been received from the following Societies:—

British Association.
Royal Dublin Society.
Royal Geographical Society.
Royal Society of Edinburgh.
Royal Physical Society of Edinburgh.
Royal Society of New South Wales.
Department of Mines, Sydney, N.S.W.
Nova Scotian Institute of Science.
Royal Institution of Cornwall, Truro
Bristol Naturalists' Society.
Cambridge Philosophical Society.
Essex Naturalists' Field Club.
Edinburgh Geological Society.
Geological Association, London.
Geological Society of London.
Leeds Philosophical and Literary Society.
Liverpool Geological Society.
Liverpool Geological Association.
Hampshire Field Club.
Hull Geological Society.
Herefordshire Natural History Society.
Manchester Geological Society.
Manchester Geographical Society.
Manchester Literary and Philosophical Society.
University Library, Cambridge.
Yorkshire Naturalists' Union.
Yorkshire Philosophical Society, York.
American Philosophical Society, Philadelphia, U.S.A.
American Museum of Natural History, New York, U.S.A.
Academy of Natural Sciences, Philadelphia, U.S.A.
Boston Society of Natural History, Boston, U.S.A.
Kansas University, Lawrence, Kansas.
Wisconsin Geological and Natural History Survey, Madison, Wis., U.S.A.
Geological Survey of Minnesota, Minneapolis, Minn., U.S.A.
Chicago Academy of Sciences.
Museum of Comparative Zoology at Harvard College, Cambridge, Mass.
New York Academy of Sciences, New York.
United States Geological Survey, Washington, D.C

Elisha Mitchell Scientific Society, University of N. Carolina, Chapel Hill, U.S.A.

New York State Library, Albany, U.S.A.

Wisconsin Academy of Sciences, Arts, and Letters.

Smithsonian Institution, Washington, D.C.

L'Academie Royale Suedoise des Sciences, Stockholm.

Societé Imperiale Mineralogique de St. Petersburg.

Societé Imperiale des Naturalistes, Moscow.

Comité Geologique de la Russie, St. Petersburg.

Instituto Geologico de Mexico.

Sociedad Cientifica "Antonio Alzate," Mexico City.

Australian Museum, Sydney.

Australian Association for the Advancement of Science, Sydney.

Natural History Society of New Brunswick.

L'Academie Royale des Sciences et des Lettres de Danemark, Copenhague.

Kaiserliche Leopold-Carol. Deutsche Akademie der Naturforscher, Halle-a-Saale.

Geological Institution, Royal University Library, Upsala.

Imperial University of Tokyo, Japan.

W. Lower Carter.

THE YORKSHIRE GEOLOGICAL AND POLYTECHNIC SOCIETY.

Statement of Receipts and Expenditure, 1st November, 1901, to 1st November, 1902.

REVENUE ACCOUNT.

Dr. — **Expenditure.**

	Expenditure	£	s.	d.
1901. Nov. 1	To Balance due to Treasurer	3	15	10
1902. Oct. 31	To Leeds Photographic Society, share of Professor Stirling's Lecture Costs	0	6	0
	,, Leeds Geological Association, share of Professor Stirling's Lecture Costs	0	13	6
	,, Printing Circulars, Programmes, etc. ...	12	0	0
	,, Printing Proceedings	58	5	7
	,, Geological Maps...	0	9	5
	,, Secretary's Postages and Petty Cash ...	8	1	1
	,, Expenses of Meetings	13	10	3
	,, Balance in hand...	15	8	10
		£112	10	6

Cr. — **Receipts.**

	Receipts	£	s.	d.
1902. Oct. 31	By Subscriptions	78	0	0
	,, Halifax Corporation Interest...	10	13	10
	,, Life Members' Subscriptions transferred from Capital A/c	12	12	0
	,, Sales of Proceedings	10	15	3
	,, Bank Interest	0	3	2
	,, Halifax Scientific Society, for Blocks ...	0	6	3
		£112	10	6

CAPITAL ACCOUNT.

	£	s.	d.
To Interest on Invested Funds transferred to Revenue A/c	10	13	10
,, Life Subscriptions transferred to Revenue A/c ...	12	12	0
,, Balance invested with Halifax Corporation ...	350	0	0
	£373	5	10

	£	s.	d.
By Balance Invested with Halifax Corporation... ...	350	0	0
,, Interest on above...	10	13	10
,, Life Subscriptions...	12	12	0
	£373	5	10

Halifax, October 23rd, 1902.

Duly audited, compared with vouchers and receipts, and found correct, and the Corporation Bonds examined.

WM. SIMPSON, *Auditor.*

J. H. HOWARTH,
Hon. Treasurer.

RECORDS OF MEETINGS.

Council Meeting, Philosophical Hall, Leeds, 27th Feb., 1902.

Chairman :—Mr. J. E. Bedford.

Present :—Messrs. P. F. Kendall, J. H. Howarth, A. R. Dwerryhouse, R. Law, E. D. Wellburn, F. W. Branson, G. Bingley, W. Ackroyd, F. F. Walton, J. W. Stather, H. Crowther, and W. L. Carter (Hon. Sec.).

The minutes of the previous Council Meeting were read and confirmed.

Letters of regret for non-attendance were read from Messrs. W. Rowley, C. W. Fennell, W. Simpson, and W. Gregson.

The Secretary read a letter from the Halifax Joint Stock Bank intimating that they had received the bond for £350 for safe custody.

A letter was read from the Treasurer (Mr. J. H. Howarth) intimating that he had secured an advance of interest from 3 to $3\frac{1}{2}$ per cent. at six months' notice, commencing on April 1st, 1902.

This arrangement was confirmed, and the Treasurer thanked for his services.

The Treasurer intimated that at the last audit there was a small balance of 18s. 4d. remaining to the credit of the Wharfedale Exploration Fund. As there did not seem any probability of the work at Grassington being resumed, and therefore it did not seem necessary to keep open the account longer, he had transferred this balance to the credit of the Society's general account. This arrangement was confirmed.

The Hon. Secretary read a letter from the Sanitary Institute asking for delegates to be appointed to the 19th Congress, to be held at Manchester, commencing on September 9th, 1902. No member of the Council being able to attend, it was resolved not to appoint a delegate.

Mr. P. F. Kendall, F.G.S., was appointed delegate to the Corresponding Societies' Committee of the British Association for the Belfast Meeting.

The Rev. W. Lower Carter, M.A., F.G.S., was appointed the Representative Governor of the Yorkshire College.

A resolution of deep regret at the decease of the Right Hon. Earl Fitzwilliam, K.G., who had been a member of the Society and a Vice-President since 1859, was passed. The Secretary was instructed to send a letter embodying this resolution to the present Earl, and inviting him to become a Vice-President in the place of his grandfather.

Mr. S. W. Cuttriss was appointed a member of the Underground Waters (Ingleborough) Committee, in the stead of Mr. J. A. Bean, removed to Newcastle-on-Tyne.

In answer to inquiries about the price of the Proceedings, it was resolved that the price to non-members and the trade should be 5s. net.

The question of the forthcoming part of the Proceedings was considered. It was resolved to publish 15 plates of fossil plants to illustrate Mr. Robert Kidston's paper.

It was resolved to hold a General Meeting and Field Excursion at Whitby, from April 25th to 29th, for an examination of the glacial features of the moorlands between Whitby and Pickering, under the leadership of Mr. P. F. Kendall.

With regard to the proposed excursion to south-east Scotland, it was decided to make Berwick-on-Tweed the centre, and to hold the excursion at the end of June, or at a date in July to suit Mr. Kendall's convenience.

On account of the Annual Meeting of the Y.N.U. being held at Hull this autumn, it was felt by the Hull members that it was not advisable to hold our Annual Meeting there this year as well. This proposal was therefore withdrawn. Harrogate and Sheffield were then nominated as places for the Annual Meeting, and on a vote Harrogate was chosen.

The following accounts were passed for payment :—

	£	s.	d.
Expenses of Mr. Stirling's lecture (share)	0	19	6
F. Carter, Stationery and Circulars ..	3	3	0
Chorley & Pickersgill, Proceedings ..	53	12	8
	£57	15	2

General Meeting at Leeds, 27th February, 1902.

A visit to the Leeds Museum was arranged to see the experiment made by the Leeds Association of Teachers, for interesting the scholars of the Leeds Elementary Schools in the Museum. A lecture was given to 400 children by Mr. Henry Crowther, F.R.M.S., and a tour round the Museum followed.

The General Meeting was held at the Leeds Institute (Chemists' Room), Mr. F. W. Branson, F.C.S., presiding, in the place of Dr. Forsyth, who was prevented by illness.

The following new members were elected :—

Mr. Stanley Nettleton, Old Roundwood, Ossett.

Mr. G. E. Stringer, jun., Slingsby Hall, York.

Letters of regret for non-attendance were read from Dr. Forsyth and Messrs. C. W. Bartholomew and J. R. Dakyns.

A paper was read by Mr. A. R. Dwerryhouse, F.G.S., on "The Glaciation of Teesdale, Weardale, and the Tyne Valley, and their Tributary Valleys," illustrated by lantern slides and diagrams.

A paper by Mr. J. R. Dakyns, M.A., on "Notes on the Glacial Phenomena of part of Wharfedale, near Grassington, from MS. written in 1878," was read by the Hon. Secretary.

Each paper was followed by a discussion.

The proceedings closed with a vote of thanks to the Chairman, and the authors of the papers.

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General Meeting and Field Excursion, Whitby, April 25th to 29th, 1902.

Friday, April 25th.—The party assembled at Goathland and visited the moorlands to the west of Newton Dale, under the guidance of Mr. P. F. Kendall, F.G.S.

The General Meeting was held at the Crown Hotel, Whitby, under the presidency of Mr. Wm. Whitaker, B.A., F.R.S., F.G.S.

The following new members were elected :—

Mr. Robert Kidston, F.R.S.E., F.G.S., Stirling.

Mr. Lewis G. Rowland, Whitby.

An address was delivered by the Chairman, who spoke of the great interest which Professor Kendall's work had aroused in London, and the value of his results to geological science.

Mr. Percy F. Kendall, F.G.S., then delivered Part I. of his lecture on "The Glacier Lake-system of the Cleveland Hills," which was illustrated by large contour maps and diagrams. A discussion followed.

Saturday, April 26th.—The party explored the moorlands to the north of Danby.

In the evening Mr. Kendall continued his lecture, describing the area between Whitby and Scarborough. A discussion followed.

Monday, April 28th.—The party drove over the moors to the west of Robin Hood's Bay and returned from Cloughton to Whitby by wagonette.

After dinner the General Meeting was resumed, when the Rev. E. Maule Cole, M.A., F.G.S., gave an account of the prehistoric entrenchments on the Wolds, illustrated by a map.

A very hearty vote of thanks was passed to the President, to Mr. Kendall for his lecture and admirable field demonstrations, and to the Rev. E. Maule Cole for his paper.

Tuesday, April 29th.—The party went to Scarborough by train and examined the deposits on the racecourse. They then proceeded by wagonette to Wykeham, and returned by way of Forge Valley and the New Cut to Scarborough, where they separated.

General Meeting and Field Excursion, Melrose, July 10th to 15th, 1902.

Chairman :—Mr. James H. Howarth, F.G.S.

Wednesday, July 9th.—The members met at the King's Arms Hotel, Melrose, and after dinner discussed the programme to be carried out.

Thursday, July 10th.—The party, under the leadership of Mr. Percy F. Kendall, F.G.S., went by train to Jedburgh. A fine section of greywacke grits overlaid by Old Red Sandstone was seen near the railway station. The agglomerate neck and the dolerite bosses to the west of Jedburgh were examined, and a visit was paid to the ancient Abbey.

Friday, July 11th.—Train was taken up Gala Water as far as Tynehead. A glacial section, revealed by a landslip, near Tynehead Station, was examined, and some rocks of possible Highland origin were found. Between Tynehead and Heriot a fine glacial overflow cutting through the watershed was examined. Between Heriot and Fontanhall sections in the Moffat shales were examined and the associated chert beds with jasper.

The General Meeting was held at the King's Arms Hotel, under the presidency of Mr. J. H. Howarth, F.G.S.

The following new members were elected :—

Professor G. R. Thompson, B.Sc., Yorkshire College.

Mr. Alfred Sykes, Woodville, Thongs Bridge, Huddersfield.

Mr. John Ibbotson, Bradfield, near Sheffield.

Letters of regret for non-attendance were read from Messrs. G. Bingley, J. Nevin, W. Whitaker, F. L. Bradley, T. Sheppard, R. Kidston, F. F. Walton, and W. H. Crofts.

A paper was read by the Rev. W. Lower Carter, M.A., F.G.S., on "The Old Red and Carboniferous Volcanoes of Southern Scotland."

A discussion followed, in which the Revs. E. Maule Cole and J. Hawell, Messrs. J. W. Stather, P. F. Kendall, and the Chairman took part. A vote of thanks was passed to the reader of the paper.

Saturday, July 12th.—The party proceeded by wagonette to Fans, where two masses of olivine dolerite were examined, and also a small neck of agglomerate, on the road to Smailholm. The programme was cut short by steady rain.

The General Meeting was resumed after dinner, when Mr. P. F. Kendall, F.G.S., gave an address on "The Glacial Problems of the Tweed Valley." A conversation followed, during which several points were discussed and explained. A hearty vote of thanks was passed to Mr. Kendall.

Monday, July 14th.—Train was taken to Earlston and the Black Hill ascended. The sanidine-trachyte was seen in a quarry lying on the top of the O.R.S. Thence the party took train to Duns, and went by wagonette to Cockburn Law, where the granite was examined. At this point an interesting instance of river-diversion was seen, the Whiteadder cutting through the igneous mass in a deep gorge.

Tuesday, July 15th.—A visit was paid to Dryburgh Abbey, and a boss of dolerite in the vicinity was examined. On the way back to Melrose a mass of platy trachyte, near Bemerside, was examined.

On separating, the most cordial thanks of the members were given to the Chairman and the Leader of the Excursions.

Meeting of the Committee for the Investigation of the Underground Waters of Ingleborough. Golden Lion Hotel. Horton-in-Ribblesdale, August 29th, 1902.

Chairman :—Mr. F. W. Branson, F.G.S.

Present :—Messrs. G. Bingley. A. R. Dwerryhouse, T. Ashley, W. L. Carter, and three visitors.

Letters of regret for non-attendance were read from Messrs. W. Simpson, R. Law, W. Ackroyd, J. H. Howarth, and S. W. Cuttriss.

The minutes of the previous Committee Meeting were read and confirmed.

Mr. Dwerryhouse read the draft report of the year's work. It was approved for presentation to the Geological Section of the British Association at Belfast.

Mr. Theodore Ashley presented a plan of Long Churn, with cross-sections. A hearty vote of thanks was passed to him for his services.

A conversation took place on the relation of the jointing of the limestone to the direction of Long Churn.

Mr. Dwerryhouse reported that there would be about £15 balance of the grant left, and it was decided to apply for the reappointment of the Committee, with power to spend this balance, which it was thought would be sufficient for next year's investigations to complete the survey of Ingleborough.

Field Work, August 29th and 30th.

The underground passages of Long Churn were traversed, and the passages plotted out on the surface with pegs and tapes. Fluorescein was introduced into the Shooting Box Stream on August 29th, but up to September 1st had not appeared. Boring was attempted at Turn Dub. Boulder clay was proved, but as it was full of boulders, the apparatus was unable to pierce it.

Council Meeting. Philosophical Hall, Leeds, 2nd October, 1902.

Chairman :—Mr. J. H. Howarth.

Present :—Messrs. R. Peach, A. R. Dwerryhouse, F. F. Walton, W. Ackroyd, P. F. Kendall, G. Bingley, F. W. Branson, and W. L. Carter (Hon. Sec.).

The minutes of the previous Council Meeting were read and confirmed.

Letters of regret for non-attendance were read from Messrs. W. Simpson, J. E. Bedford, J. W. Stather, E. D. Wellburn, and J. T. Atkinson.

Arrangements for holding the Annual Meeting at the George Hotel, Harrogate, were made.

It was decided to take a Field Excursion on the morning of the day of the Annual Meeting, to view Cayton Gill and the Gorge of the Nidd at Knaresborough.

The names of Officers and Council were considered, and a list of nominations was adopted and ordered to be sent to the members.

The Treasurer made a brief financial statement.

The following account was passed for payment :—

	£	s.	d.
F. Carter (stationery, circulars, and maps)	8	17	0

Resolved that £12 12s. be transferred from the Capital Account to the General Account.

Applications were made for the loan of blocks from the Proceedings by Mr. J. W. Stather, for the Hull Geological Society, to illustrate an abstract of Mr. Croft's paper on the Alexandra Dock Extension, and by Mr. T. Sheppard for blocks on the East Riding to illustrate his book on the Geology of the Yorkshire Coast.

It was resolved to grant these applications on the condition that proper acknowledgment was made in the text of the papers, and that, in the case of photographs, the permission of the photographer was obtained.

A letter was read from Earl Fitzwilliam, acknowledging the vote of sympathy of the Council on the death of the late Earl Fitzwilliam, K.G., and accepting the position of Vice-President of the Society in the place of his grandfather.

In answer to an inquiry of the Hon. Secretary, permission was given him to supply back numbers of the Proceedings to members desiring to complete their sets, at half price.

It was decided to hold a Spring General Meeting at Leeds, in conjunction with the Council Meeting, General Meetings and Field Excursions at Horton-in-Ribblesdale and Cromer, and the Annual Meeting at Hull.

The Secretary read an abstract of the Annual Report, which was approved for presentation to the Annual Meeting.

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Meeting of the Underground Waters (Ingleborough) Sub-Committee, Leeds, 2nd October, 1902.

Chairman :—Dr. D. Forsyth.

Present :—Messrs. S. W. Cuttriss, W. Ackroyd, F. W. Branson, P. F. Kendall, F. F. Walton, G. Bingley, A. R. Dwerryhouse, and W. L. Carter (Hon. Secretary).

The minutes of the preceding Committee Meeting were read and confirmed.

Mr. A. R. Dwerryhouse, Secretary to the B.A. Committee, reported on the work done during the summer in investigating and surveying Long Churn and the springs on the slopes of Simon's Fell. Fluorescein had been again put into the Shooting Box stream, but no results had been seen at any spring. The course of several streams to the north of the Shooting Box, and a crossing of an upper and lower line of drainage, had been determined by means of fluorescein. The connection of Alum Pot with Turn Dub had been established, but the borings at Turn Dub had not been successful. About eight or ten feet of alluvium had been pierced, and then boulder clay was reached, which, being crowded with stones, could not be pierced with the apparatus used.

He reported that the Belfast Meeting of the British Association had granted £40 for the completion of the investigations.

The work to be undertaken during the next year was then considered. It was decided to investigate thoroughly the Shooting Box stream, Long Kin West, Moses' Spring, and Grey Wife Sike. Also that one or two bore-holes should be put down near Turn Dub by a well-sinker, at an expense not exceeding £25.

Resolved also that the underground survey of the passages to the west of Long Churn should be undertaken, and that Mr. Theodore Ashley be invited to undertake this work.

Mr. S. W. Cuttriss gave some interesting facts about a recent descent of Alum Pot by the Yorkshire Ramblers' Club, exhibited a plan of the Pot, and gave details of the beds of limestone observed in the descent.

Annual General Meeting, George Hotel, Harrogate, 30th October, 1902.

The Marquis of Ripon, K.G., F.R.S., President, in the chair.

Letters of regret for non-attendance were read from Messrs. J. Turner Taylor (Town Clerk), G. Paul (Borough Meteorologist), F. Bagshaw (Borough Engineer and Surveyor,) Dr. Ward (Medical Officer of Health), R. Peach, J. H. Howarth, J. T. Atkinson, W. Gregson, and G. H. Parke.

The Hon. Secertary read an abstract of the Annual Report.

The Financial Statement was presented by Mr. W. Simpson, F.G.S. (Auditor), in the absence of the Treasurer.

First Resolution :—" That the Report and Financial Statement be adopted and printed in the Proceedings." Proposed by Mr. M. B. Slater, seconded by Mr. J. W. Sutcliffe, and carried.

Second Resolution :—" That the best thanks of the Society be given to the President, Vice-Presidents, Officers, Members of Council, and Local Secretaries, for their conduct of the affairs of the Society during the past year." Proposed by Mr. E. Hawkesworth, seconded by Mr. J. E. Bedford, and carried.

The following new members were elected :—

Mr. Thomas Beach, Hillfield, Castleford.

Mr. Edward Wilson Dixon, M.I.C.E., 14, Albert Street, Harrogate.

Mr. Samuel Stead, 33, James Street, Harrogate.

Third Resolution :—" That the Most Hon. the Marquis of Ripon be elected President for the ensuing year." Proposed by the Rev. C. T. Pratt, M.A., seconded by Mr. Walter Rowley, F.G.S., and carried.

Fourth Resolution :—" That the following be elected to serve as Vice-Presidents, Officers, and Local Secretaries for the ensuing twelve months." Proposed by Mr. W. Ackroyd, F.I.C., seconded by Mr. A. Millward, and carried.

President :

The Marquis of Ripon, K.G.

Vice-Presidents :

Earl Fitzwilliam.
Earl of Wharncliffe.
Earl of Crewe.

Viscount Halifax.
H. Cilfton Sorby, LL.D., F.R.S.
Walter Morrison, J.P.
W. T. W. S. Stanhope, J.P.
James Booth, J.P., F.G.S.
F. H. Bowman, D.Sc., F.R.S.E.
W. H. Hudleston, F.R.S.
J. Ray Eddy, F.G.S.
David Forsyth, D.Sc., M.A.
Walter Rowley, F.G.S., F.S.A.
Lord Masham.
Sir Christopher Furness, M.P., D.L.

Treasurer :

J. H. Howarth, F.G.S.

Hon. Secretary :

William Lower Carter, M.A., F.G.S.

Hon. Librarian :

Henry Crowther, F.R.M.S.

Auditor :

W. Simpson, F.G.S.

Local Secretaries :

Barnsley—T. W. H. Mitchell.
Bradford—J. E. Wilson.
Driffield—Rev. E. M. Cole, M.A., F.G.S.
Halifax—W. Simpson, F.G.S.
Harrogate—Robert Peach.
Hull—John W. Stather, F.G.S.
Leeds—H. Crowther, F.R.M.S.
Middlesbrough—Rev. J. Hawell, M.A., F.G.S.
Skipton—J. J. Wilkinson.
Thirsk—W. Gregson, F.G.S.
Wakefield—C. W. Fennell, F.G.S.
Wensleydale—W. Horne, F.G.S.
York—Rev. W. Johnson, B.A., B.Sc.

Fourteen names having been nominated for election on the Council, a ballot was taken, which resulted in the election of the following gentlemen, Messrs. W. Simpson and J. H. Lofthouse being the Scrutineers :—

Council :

W. Ackroyd, F.I.C.	A. R. Dwerryhouse, F.G.S.
J. T. Atkinson, F.G.S.	Edwin Hawkesworth.
J. E. Bedford, F.G.S.	P. F. Kendall, F.G.S.
Godfrey Bingley.	Rev. C. T. Pratt, M.A.
F. W. Branson, F.I.C.	F. F. Walton, F.G.S.
W. Cash, F.G.S.	E. D. Wellburn, F.G.S.

The President delivered an address.

The Report of the Committee for the investigation of the Underground Waters of Ingleborough was read by Mr. A. R. Dwerryhouse, B.Sc., F.G.S. There was a short discussion on the Report.

A paper was read by Mr. Percy F. Kendall, F.G.S., on "The Western Margin of the Uredale Glacier, and a System of Glacier-lakes near Ripon and Harrogate." This was followed by a discussion.

A series of new lantern slides of geological interest was exhibited and described by Mr. Godfrey Bingley.

Fifth Resolution :—"That this Meeting desires to convey its hearty thanks to the Marquis of Ripon, for presiding; to Mr. P. F. Kendall, F.G.S., for leading the excursion; to the Readers of the Papers; and to Mr. Godfrey Bingley, for his exhibition of lantern slides." Proposed by the Rev. E. Maule Cole, M.A., F.G.S., seconded by the Rev. J. Hawell, M.A., F.G.S., and carried.

The members and their friends dined together at the George Hotel, under the presidency of Mr. Walter Rowley, F.S.A., F.G.S., in the unavoidable absence of the Mayor of Harrogate.

Earlier in the day the members drove from Harrogate by wagonette to Dole Bank, near Markington, under the leadership of Mr. P. F. Kendall, F.G.S., to examine the inlet of a great lake-overflow, Cayton Gill. The party walked down Cayton Gill, and noted the interesting diversion of Markington Beck, after which they returned to Harrogate.

VOL. XV.] [PART II.

PROCEEDINGS

OF THE

YORKSHIRE

GEOLOGICAL AND POLYTECHNIC SOCIETY.

EDITED BY W. LOWER CARTER, M.A., F.G.S.,

AND WILLIAM CASH, F.G.S.

1904.

THE GLACIATION OF THE BRADFORD AND KEIGHLEY DISTRICT.

BY ALBERT JOWETT, M.SC., AND H. BRANTWOOD MUFF, B.A., F.G.S.

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 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, *viâ* 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 Powerloom 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.

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* 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.

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* 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 over-ridden 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).
ıııııııııı	,,	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 $1\frac{1}{4}$ 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 Lakê, 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

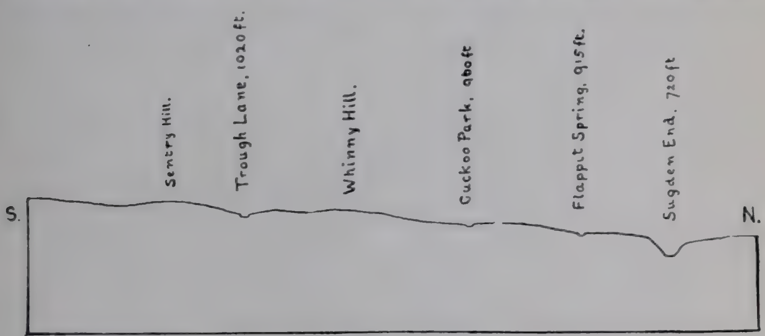


Fig. 1.

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

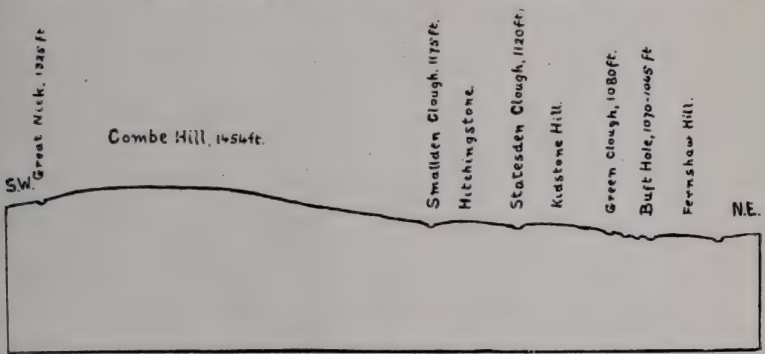


Fig. 2.

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 $1\frac{1}{4}$ 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.

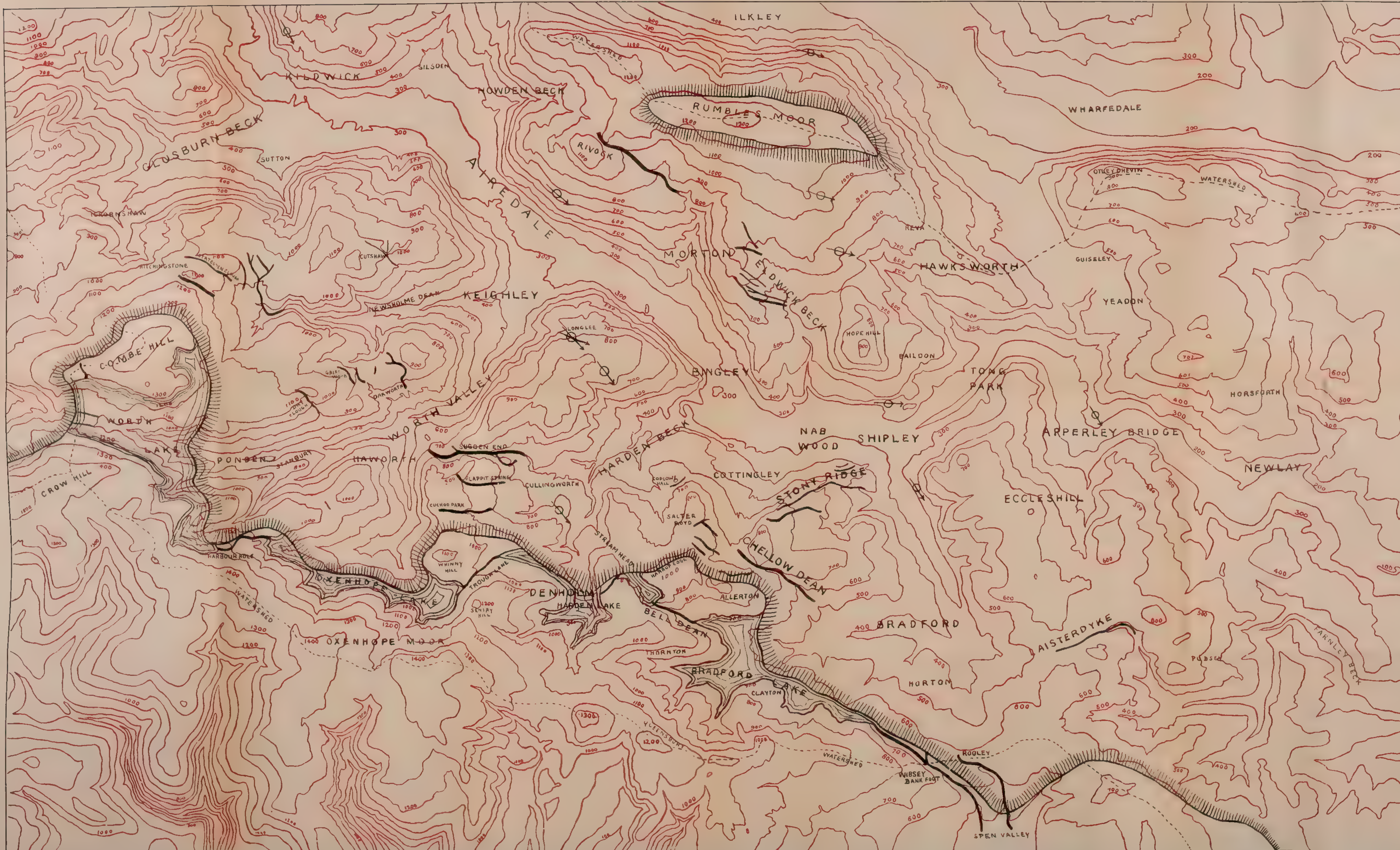
The position and direction of the striated rock-surfaces on Harden Moor, the packing of the till on the south-eastern slopes of the hills, and the distribution of Carboniferous Limestone and Silurian boulders, prove a general ice-movement from the north-west not only down the main valley of the Aire, 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



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

CONTOURED MAP OF PART OF AIREDALE.

Scale: 1½ inch to 1 mile.

Overflow Channels. Edge of the Ice near its Maximum Extension. Striated Rock-surfaces.

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.

THE UNDERGROUND WATERS OF NORTH-WEST YORKSHIRE.

PART II. THE UNDERGROUND WATERS OF INGLEBOROUGH.

I. Introduction.

On the completion of Part I. of this investigation, which dealt with the Sources of the Aire* at Malham, it was resolved to continue the investigations in conjunction with a Committee appointed by the British Association, of which Professor W. W. Watts was the Chairman. A working arrangement was entered into by which the Yorkshire Geological and Polytechnic Society agreed to carry on the work as heretofore by means of its own members, and to present an abstract of the results to the British Association from time to time through Mr. A. R. Dwerryhouse, M.Sc., F.G.S., the Secretary of the B.A. Committee for the Investigation of the Underground Waters of Craven, and that the complete report, fully illustrated, should be published in the Proceedings of the Yorkshire Geological and Polytechnic Society. The area of the Ingleborough massif was considered to be the most suitable for the further investigations of the Committee, as it presented a complete problem to be considered, all the water falling on the higher parts of the mountain being gathered into streams which fell into potholes along the line of junction of the overlying beds with the main mass of the Carboniferous Limestone, and were given out again in a series of underground streams and springs round its flanks.

Professor W. W. Watts, on behalf of the British Association Committee, promised very cordial co-operation in this further scheme of investigation, and a Committee, in which all the members of the British Association Committee were included, was appointed by the Yorkshire Geological and Polytechnic Society to undertake the work. The following gentlemen formed the Committee :—Messrs. W. Ackroyd, F.I.C. (Halifax), J. A. Bean, F.G.S. (Wakefield), F. W. Branson, F.I.C. (Leeds), B. A. Burrell, F.I.C. (Leeds), G. H. Brown (Settle), Godfrey

* Proceedings Yorks. Geol. and Polytec. Soc., XIV., p. 1.

Bingley (Headingley), Ed. Calvert (Buxton), S. W. Cuttriss (Leeds), J. A. Farrer, J.P. (Clapham), C. W. Fennell, F.G.S. (Wakefield), J. W. Handby (Austwick), J. H. Howarth, F.G.S. (Halifax), R. Law, F.G.S. (Hipperholme), W. Simpson, F.G.S. (Halifax), F. Swann, B.Sc. (Ilkley), J. W. Tate, M.E. (Ingleton), W. M. Watts, D.Sc. (Giggleswick), J. J. Wilkinson (Skipton), J. E. Wilson (Ilkley), and the members of the B.A. Committee, Professor W. W. Watts (Chairman), Mr. A. R. Dwerryhouse (Secretary), Professor Smithells, and Messrs. W. Morrison, M.P., G. Bray, T. Fairley, P. F. Kendall, J. E. Marr, F.R.S., Revs. E. Jones and W. Lower Carter. The Rev. W. Lower Carter was appointed Secretary of the complete Committee.

The Committee was originally formed for the Investigation of the Underground Waters of Craven, but as Ingleborough is outside the district of Craven, it was decided to enlarge the title of the Committee to that of the Committee for the Investigation of the Underground Waters of North West Yorkshire, and under that title the results of the Malham investigations were published.

The first meeting of the Committee was held at Clapham, on April 27th, 1900, under the presidency of Mr. J. A. Farrer, J.P. There were present Messrs. F. W. Branson, J. H. Howarth, P. F. Kendall, R. Law, W. Simpson, J. W. Tate, J. J. Wilkinson, S. W. Cuttriss, E. Calvert, W. L. Carter (Secretary), and a few visitors. The work to be done and the best methods of attacking it were freely discussed, and a plan of action for the following day was decided on. Mr. Branson had been previously authorized by the Malham Sub-committee to call a meeting of the chemists on the Committee to consult as to the tests to be applied, and to arrange for their preparation and conveyance to Clapham.

On the following day the Committee proceeded to test Gaping Ghyll, Long Kin East, and other pots on the Allotment, many of which were unfortunately found to be dry, in which operations, and in the long series of investigations that followed, they were generously and efficiently assisted by Messrs. T. A. Clapham, F.R.A.S., of Austwick, J. Bateman, H. Harrison, E. Spence, T. Carlile, of Clapham, and other local gentlemen. Messrs. Clapham, Bateman, Spence, Harrison, and Campbell took a special part in the tedious work of watching streams and collecting samples for analysis. The operations are fully recorded under another division of this Report, and so need not be detailed here.

It was resolved to appoint a Sub-committee, as was done in the case of the Malham investigation, to make arrangements for the continuance of the work and its proper oversight. The following members were elected to form that Sub-committee :—Messrs. Fennell, Bean, Ackroyd, Kendall, Howarth, Dwerryhouse, and Carter (Secretary). Subsequently on the removal of Mr. Bean to Newcastle his place was taken by Mr. S. W. Cuttriss.

On May 17th this Sub-committee met and decided to issue a brief statement of the results of the investigations to date to the members of the General Committee and to the Press, and Messrs. Branson and Carter were requested to prepare this statement.

The second meeting of the full Committee was held at Clapham on June 8th, 1900, under the presidency of Dr. David Forsyth. There were present Messrs. Ackroyd, Branson, Dwerryhouse, Bingley, Fennell, Kendall, Fairley, Swann, Law, and Carter (Secretary). It was decided to test "The Abyss," in Ingleborough Cave, Grey Wife Sike, and two pots on the Allotment. This was carried out as detailed further on.

At a meeting of the Sub-committee on August 3rd, Mr. Ackroyd presented the report of the second series of tests in the Clapham area. The report was adopted with the best thanks of the Committee to the chemists for their arduous labours, and the papers were handed to Mr. Dwerryhouse for the results to be embodied in a report to the Bradford Meeting of the British Association.

The Sub-committee met on October 18th, when Mr. Dwerryhouse read the report that had been presented to the Geological Section of the British Association at Bradford. It was agreed that the next tests should be made on the western side, fluorescein to be introduced into a pot on Ravenscar. Mr. Dwerryhouse and Mr. Howarth to arrange, in conjunction with Mr. J. W. Tate.

On March 21st, 1901, Mr. Dwerryhouse reported the results of the tests at Crina Bottom, and it was resolved to test Alum Pot on Saturday, March 30th.

On October 31st, the Sub-committee met in Leeds, when Mr. Dwerryhouse read the report which he had presented to the Glasgow Meeting of the British Association. He also reported on the results of the tests at Alum Pot, and announced the connection between Alum Pot, Footnaws Hole, and Turn Dub. It was resolved to continue the investigation of the western area, and to put down a bore hole near Turn Dub, in order to ascertain the depth of the drift. It was decided to accept the assistance kindly offered by Mr. Theodore Ashley, Mining Engineer, of Leeds, in surveying Long Churn and its connecting passages.

The third meeting of the full Committee was held at Horton-in-Ribblesdale, on August 29th, 1902, under the presidency of Mr. F. W. Branson. Mr. Dwerryhouse read a draft report of the year's work, which was approved for presentation to the British Association at the Belfast Meeting. Mr. Theodore Ashley exhibited and described a plan of Long Churn with cross sections. A hearty vote of thanks was passed to him for his services. A conversation took place as to the relation of the jointing of the limestone to the direction of the chief passages in Long Churn.

The members of the Committee, led by Messrs. Dwerryhouse and Ashley, traversed part of the underground passages of Long Churn and plotted them out on the surface with tapes and pegs. Boring was attempted at Turn Dub, and boulder-clay was proved, but it was so crowded with large boulders that the apparatus could not pierce it.

The Sub-committee met on October 2nd, 1902, when Mr. Dwerryhouse reported on the work accomplished during the summer in surveying and investigating Long Churn and the springs and channels in the neighbourhood of Alum Pot. The course of several streams north of the Shooting Box stream had been determined by fluorescein, and the crossing of an upper and a lower line of drainage had been established.

The work to be undertaken during the next year was considered. It was decided to investigate thoroughly the Shooting Box stream, Long Kin West, Grey Wife Sike, and the source of Moses' Well, and to have two bore holes put down in the vicinity of Turn Dub by a well sinker. It was resolved that the survey of the passages to the west of Long Churn should be undertaken, and that Mr. Ashley be invited to co-operate with the Committee in this work. Mr. S. W. Cuttriss gave some interesting facts about the recent descent of Alum Pot by members of the Yorkshire Ramblers' Club, and exhibited a plan of the pot and gave details of the beds observed during the descent.

The fourth meeting of the full Committee was held at Horton-in-Ribblesdale, on April 24th, 1903. Mr. Dwerryhouse reported that owing to Mr. Ashley's removal from Leeds he could not continue the work of the survey of Long Churn. It was resolved that Mr. Dwerryhouse should have the services of an assistant to complete it. The Committee, under the guidance of Mr. Dwerryhouse, inspected Long Churn, Turn Dub, and other points connected with the investigation.

The Sub-committee met on July 15th, 1904, under the presidency of Mr. F. W. Branson. Mr. Dwerryhouse reported the condition of the work. The Shooting Box stream had at last yielded up its secret, and had been traced to Crummack Beck Head. The courses of several streams previously undetermined had now been ascertained. Messrs. Dwerryhouse, Howarth, Bingley, and Carter, were appointed an Editorial Committee to arrange the report for publication.

The fifth meeting of the full Committee was held at Leeds, on December 1st, 1904, Mr. J. H. Howarth in the chair.

The Secretary, Rev. W. Lower Carter, stated that he had obtained an estimate for the cost of the illustrations needed for the Ingleborough Report, which amounted to £38. It was resolved that a special fund should be raised to defray this expenditure.

The draft report was read by Mr. Dwerryhouse and amended. The selection of the illustrations and other details were left with

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

Reproduced from the Ordnance Survey Map with the sanction of the Controller of H.M. Stationery Office.

the Publication Committee, and were dealt with at a subsequent meeting.

The efforts of the Committee to raise a special fund for the adequate illustration of the Report. with maps, plans, sections, and photographs, was generously responded to by a number of members of the Committee and of the Yorkshire Geological and Polytechnic Society, and the Committee offer their best thanks to the Marquis of Ripon, Lord Masham, Sir Walter Spencer-Stanhope, K.C.B., Dr. H. Clifton Sorby, F.R.S., Sir T. Brooke, Bart., Dr. D. Forsyth, Messrs. Walter Morrison, George Bray, J. H. Howarth, Walter Rowley, G. Bingley, F. W. Branson, W. Simpson, W. Ackroyd, J. J. Wilkinson, R. Law, W. H. Huddleston, F.R.S., W. Robinson, John Farrah, J. W. Farrah, H. C. Embleton, A. H. Pawson, J. Norton Dickons, C. F. Tetley, E. H. Tetley, T. Fairley, B. A. Burrell, Rev. C. T. Pratt, and other gentlemen, by whose generous help they have been enabled to publish the results of the Committee's investigations in a far more complete way than could have been possible otherwise.

The sincere thanks of the Committee are due and are hereby offered to all those who have taken part in this work; and they wish specially to put on record their extreme obligations to Mr. Arthur R. Dwerryhouse, M.Sc., F.G.S., by whom the rest of this Report has been drawn up, for his unremitting labours in the prosecution of this great task. To it he has devoted an immense amount of time, labour, and thought, and it is largely to this that the completeness of the Report is due.

They also desire to acknowledge the cordial co-operation of the members of the British Association Committee, and the generous grants of money voted by that Association, without which it is improbable that the investigations would have been brought to a successful conclusion.

W. Lower Carter.

II. Geography and Geology of the District.

In the Memoir of the Geological Survey on the country around Ingleborough the geology of the area under consideration is fully treated. Also in Volume XIV., Parts II. and III., of these Proceedings will be found an account of the Physical Geography and Geology of Ingleborough from the pen of Professor T. McKenny Hughes. To these works those readers who wish to make a detailed study of the same are referred. Other papers on the subject are mentioned in the Bibliography of the Yorkshire Caves by Mr. S. W. Cuttriss, which follows this Report.

In the following pages it is intended to give such an outline of the geography and geology of the area as is necessary for the proper understanding of the work of the Committee on the circulation of the underground waters of the district.

Ingleborough forms a bold hill 2,373 feet in height, and is an outlying spur of the Pennine Range. It is separated from its neighbours on the East by the Valley of the Ribble, from those on the south by that of the Wenning, and from Whernside on the west by Chapel-le-Dale. It forms therefore a roughly triangular patch of high ground separated from surrounding hills by deep valleys, and on this account was chosen as a suitable area for the investigation of the movements of underground water, inasmuch as these movements were unlikely to be complicated by any flow of water from the neighbouring heights.

The area is also suitable for an investigation such as the present, on account of the large number of streams which flow for some portion of their courses beneath the surface of the ground. Indeed, every stream which courses down the upper slopes of Ingleborough sooner or later sinks into the limestone which forms the base of the hill, to emerge in one of the surrounding valleys.

On reference to the accompanying map and sections, Pl. XXIII., and Figs. 1 and 2, it will be seen that the summit of the hill consists of Millstone Grit, resting upon a series of shales with thin limestones and grits (Yoredale Rocks), which in turn lie upon the great mass of the Mountain Limestone which is here 600 to 700 feet in thickness. At the base of this formation is a great unconformity, and below this are highly folded and inclined rocks of Ordovician and Silurian age.

Proc Yorks Geol and Polytec Soc, Vol XV, Plate XXIII

GEOLOGICAL MAP OF INGLEBOROUGH DISTRICT.

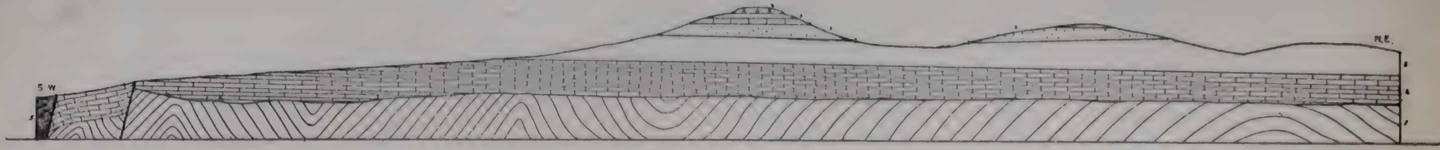


Fig. 1.

SECTION ACROSS INGLEBOROUGH FROM S.W. TO N.E.

1. Ordovician and Silurian. 2. Carboniferous Limestone. 3. Yoredale Series. 4. Millstone Grit. 5. Coal Measures.

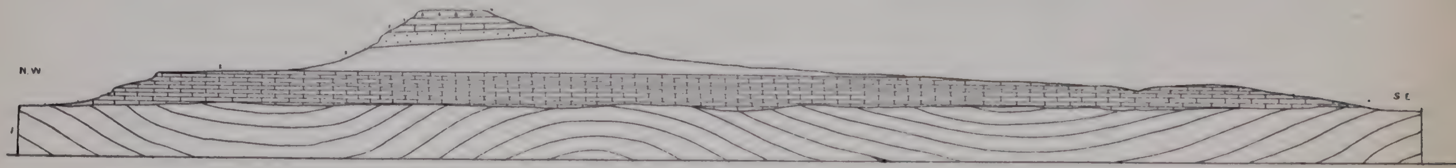


Fig. 2.

SECTION ACROSS INGLEBOROUOH FROM N.W. TO S.E.

1. Ordovician and Silurian. 2. Carboniferous Limestone. 3. Yoredale Series. 4. Millstone Grit.

The Millstone Grit is a porous sandstone, and rain falling upon its surface is readily absorbed and percolates through its mass until the underlying shales are reached. Here its downward progress is arrested and it breaks out as a series of springs, the waters of which course down the steep slopes of the Yoredale Rocks until they reach the great plateau of the Mountain Limestone.

This limestone is hard, crystalline, and quite impervious to water in the ordinary sense, but, owing to the fact that it is highly jointed, all water flowing on to its surface is at once absorbed into the cracks and fissures.

The manner in which the joint fissures are enlarged by the solvent action of the rain water so as to form a series of fissures will be better understood by a reference to Pl. XXXVI., Figs. 1 and 2.

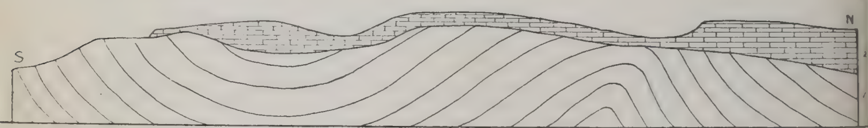


Fig. 3.

SECTION THROUGH MOUGHTON FROM N. TO S., TO SHOW RIDGES ON THE SILURIAN FLOOR.

1. Ordovician and Silurian. 2. Carboniferous Limestone.

The Ordovician and Silurian rocks consist for the most part of hard grits and slates which are practically impervious, the result being that the waters which flow into the Mountain Limestone on its upper surface are arrested in their downward course, and issue as springs either upon or immediately above the line of junction between the limestone and the underlying impervious rocks.

It must be noticed in passing that the surface of older rocks on which the limestone rests is by no means horizontal, but consists of a series of ridges with intervening valleys having a general N.W. to S.E. trend (Fig. 3 and Pl. XL.).

These ridges beneath the limestone have, as the sequel will show, an important effect upon the direction of flow of the subterranean streams.

The surface of the country is partly covered by mounds and ridges of boulder-clay and gravel of Pleistocene age, the product of a system of great glaciers which flowed round Ingleborough from the high ground to the north of Ribblehead.

The boulder-clays offering great resistance to the passage of water have in several instances considerably modified the courses of the streams both surface and subterranean, but as detailed reference will be made to these cases in Section III. it is unnecessary to discuss them at this stage.

The glacial deposits have been described in the Geological Survey Memoir on the country round Ingleborough, and by Mr. J. G. Goodchild,* but the glacial drainage of the district has not been fully worked out as yet, and it is therefore impossible to come to any definite conclusions with regard to the direct effect of the glaciers themselves upon the subterranean streams.

It can, however, be definitely stated that some of the existing pot-holes and caves are of pre-glacial origin, while it seems possible that others which are now deserted by the streams, were produced *during* the glacial period by streams diverted from their original (and subsequent ?) course by the edge of the glacier, or by streams flowing off the ice itself.

Further references to this most interesting topic will be made in Section III.

In a country where not only the small tributary streams, but in some cases even the rivers themselves, pass underground for considerable distances, it is difficult to draw lines upon the map which shall represent the watersheds of the district, and, as the sequel will prove, if such lines be drawn by the ordinary method they will give erroneous results, since, in more than one instance, the water during its underground journey travels parallel or even counter to the slope of the surface, occasionally passing beneath a ridge to emerge in a neighbouring valley. In this way, water which, from its direction of flow and from the slope of the ground, would inevitably flow into the River Ribble if it continued its course on the surface, sinks into the

* Notes on the Glacial Phenomena of Upper Ribblesdale. The Naturalist, August 1892.

limestone, passes into a tributary of the Wenning and so eventually joins the River Lune.

It may be mentioned that the terms "pot" and "pot hole" are used locally to signify the deep chasms down which the surface streams plunge, while the terms "enters," "shake hole," "water swallow" are used indifferently on the Ordnance Maps to indicate smaller openings of a similar nature or even those funnel-shaped hollows otherwise known as swallow-holes, which are such a well-known feature of all moors with limestone below the surface soil.

III. The Underground Waters.

In the earlier years of the investigation, the work was carried on by large parties of workers, who assembled at some point in the district and proceeded to investigate a number of streams simultaneously.

This was accomplished by the use of various test substances introduced at the water sinks. A watch was then set at all the springs which were thought to be possible outlets.

As some of the substances employed were not visible in the springs, but could only be detected by means of chemical reagents, it was necessary to collect samples from a large number of springs at frequent intervals.

The labour involved in the collection of samples and the subsequent examination was so great (1,200 tests were made during a single season) that it was decided to employ colouring matters only, as these could be readily seen in the field, and so the work of watching was minimised and that of testing entirely obviated.

This, of course, reduced the number of streams which could be treated simultaneously and consequently largely increased the time necessary to complete the work; but at the same time it became possible to employ much smaller working parties with the result that the meetings could be held more frequently.

When the main lines of the underground drainage had been determined, it became possible to work several streams at once, provided these were chosen sufficiently far apart to exclude any possibility of interference with each other, even though the same reagent was employed.

The following substances were employed as tests during the investigation :—

1. Common Salt.
2. Ammonium Sulphate.
3. Methylene Blue.
4. Fluorescein.

1. *Common salt* was introduced in quantities of half a ton at a time, and the issuing waters were tested quantitatively for chlorine by means of a standard solution of nitrate of silver, the end reaction being observed by means of potassium chromate.

Similar tests were made on the water issuing from the springs prior to the introduction of the salt, in order to ascertain the normal amount of chlorine present in each case.

Curves were then drawn to indicate the fluctuation of the chlorine percentage during such period as was thought necessary by the Committee.

This was found to be a satisfactory method, except in that it involved much labour in collecting and testing samples as well as in the transport of the salt to the sinks, many of which are situated on the hill sides, distant from any road or even track.

2. *Ammonium sulphate* was employed in quantities of about 5 cwt., the springs being tested by means of Nessler's solution. In this case also "blank tests" were made before the introduction of the ammonium sulphate.

This method possesses all the disadvantages of the foregoing, with the additional one that the quantity of ammonia in streams flowing through an agricultural district varies with changes of weather.

There are one or two instances in this district in which every large shower carries the washings of a farmyard into the neighbouring stream, raising its ammonia percentage considerably, and thus rendering the tests with ammonium sulphate less certain in this area.

3. *Methylene Blue.*

This substance was tried on several occasions, but was found to be useless for the purposes of the Committee, as it invariably failed to put in an appearance, although the same streams readily responded when fluorescein was used.

4. *Fluorescein.*

This reagent, dissolved in a solution of potassium carbonate, has been found to be by far the most useful and trustworthy.

Its appearance in a stream is unmistakable, except in cases where it is very dilute, and the stream is at the same time coloured strongly brown by peat. Even in this case, however, it can be detected by the practised eye, especially if there be bright sunshine at the time.

During the last four years fluorescein has been the only test employed by the Committee.

In a few cases the underground course of the water was actually followed, but in most cases this was found to be impossible owing to the narrowness of the fissures.

Accounts of such passages as it was possible to explore will be found in the following pages.

Since the work was commenced at Gaping Ghyll, it will be convenient to start the description at the same point. The arrangement of the following pages will on the whole, however, follow geographical rather than chronological lines, starting at Gaping Ghyll and working round by Alum Pot, Ribblehead, Chapel-le-Dale, and Ingleton.

Gaping Ghyll. (P 3.)* [Pls. XXII. and XXVI.]

Fell Beck is formed by the union of three principal and several smaller streams at Fell Beck Head. The three larger streams rise as springs on Simon Fell Breast, at a height of about 2,100 feet O.D.

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* The figures given in round brackets refer to the accompanying plans and maps. "P" signifies Pot-hole or water sink, and "S" is used to indicate Spring.

Lower down it receives several other streams on its right bank and finally flows on to the Mountain Limestone at an elevation of 1,350 feet. Almost immediately on entering the limestone area the stream commences to sink. It goes to no great depth however, as it reappears several times within a distance of 50 yards. It then flows over the lip of a roughly circular, well-like abyss—the well-known Gaping Ghyll Hole.

In wet weather, the bed of the Fell Beck, between the point where it flows on to the Mountain Limestone and Gaping Ghyll, is entirely occupied by the stream, but in drought and moderate weather there are several dry stretches as described above. In either case the destination of the water is the same, it plunges down into the great crater-like pit of Gaping Ghyll (Pls. XXXI. and XXXII.) to a depth of 365 feet from the surface.

The descent of Gaping Ghyll was first made by Mr. John Birkbeck, of Settle, in 1872; he, however, was unable to penetrate further than the ledge (see Plate XXIV.) in the main hole 190 feet from the surface.

The first complete descent was made in August, 1895, by Mons. E. A. Martel, of Paris, who succeeded in reaching the bottom by means of rope ladders.

The "pot" was descended by members of the Yorkshire Ramblers' Club in May, 1896, when extensive surveying operations were undertaken in the large chamber at the bottom of the shaft, and in the passages leading therefrom, the results of which we are enabled to present in Fig. 4 and Pl. XXIV. by the courtesy of the Committee of the Yorkshire Ramblers' Club.

As it was found impossible to complete the survey on this occasion a descent was made at Whitsuntide, 1903, on which occasion three members of the Underground Waters' Committee* were enabled, by the kindness of the club, to make the descent.

Full accounts of the various descents and of the chambers and caverns explored will be found in the Yorkshire Ramblers' Club Journal.†

* Mr. S. W. Cuttriss, Mr. A. R. Dwerryhouse, and Prof. Kendall.

† Vol. I., pp. 65-74, 123-133; Vol. II., pp. 48-51.

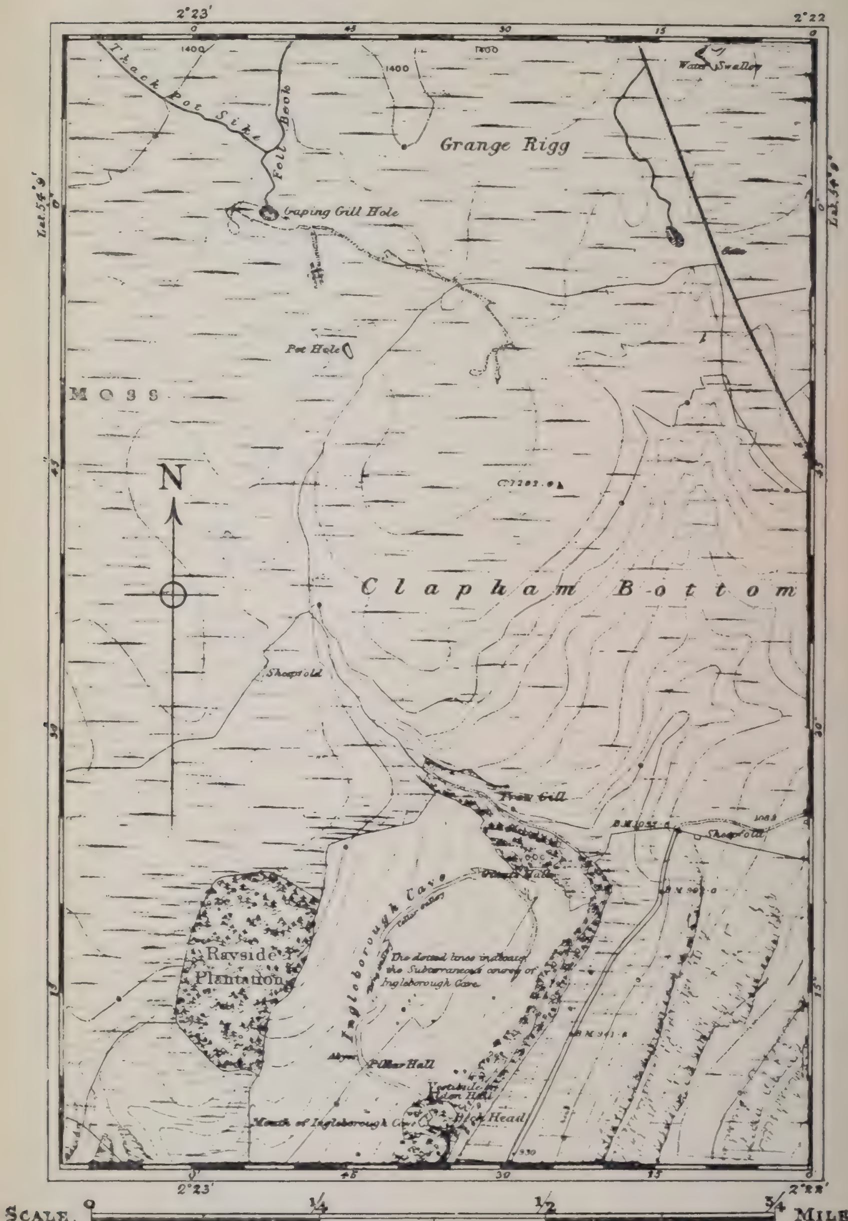
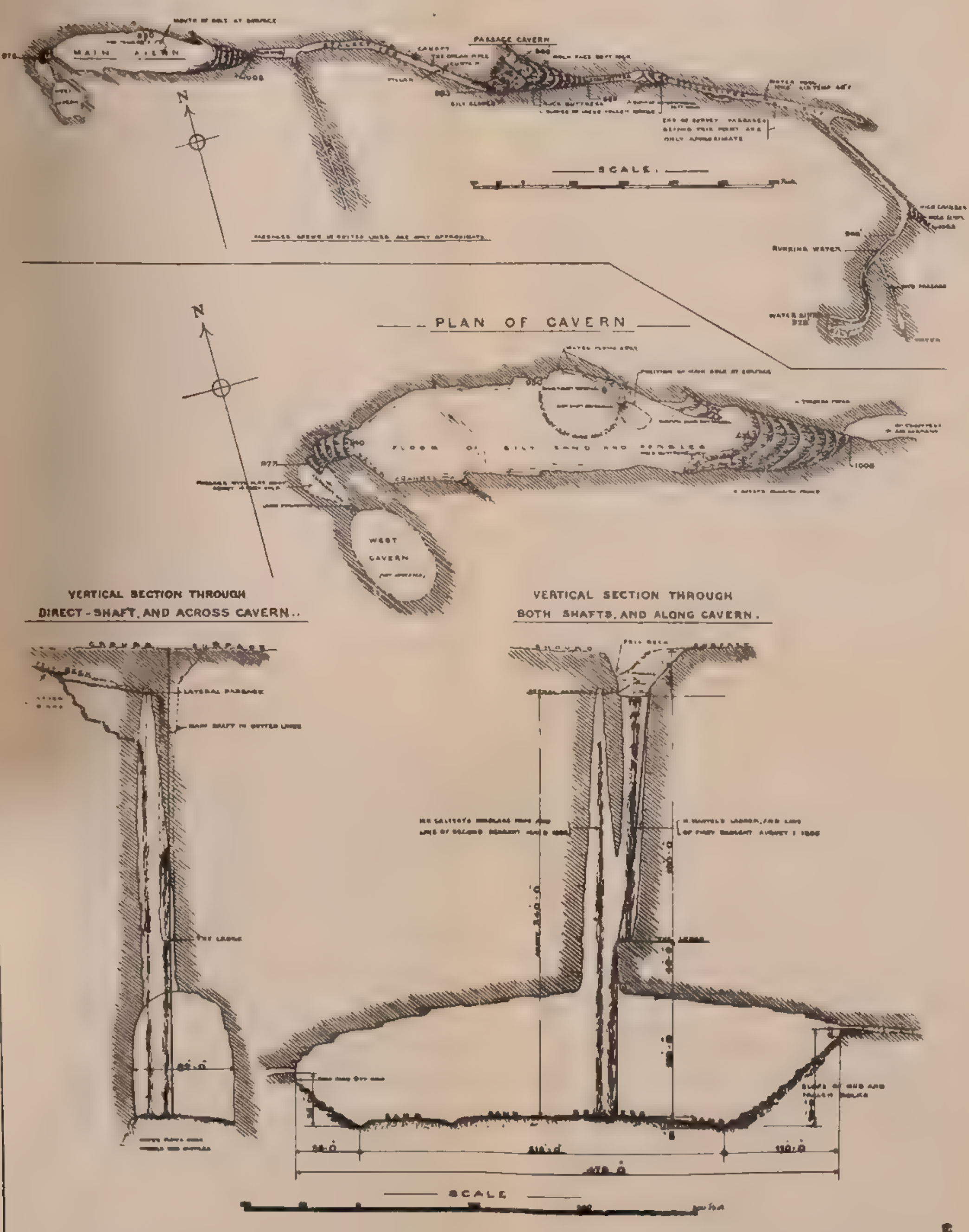


Fig. 4.

From the Yorkshire Ramblers' Club Journal, by permission.

GAPING GHYLL CAVERN AND PASSAGES.

FROM SURVEYS MADE IN MAY 1896.



From the Yorkshire Ramblers' Club Journal, by permission.

At the bottom of the shaft is an enormous chamber measuring 479 feet in length by 82 feet in breadth and 110 feet in height.

The water which enters partly over the lip of the Hole, and partly by a subterranean waterfall about 30 feet below the surface, sinks through the floor of the chamber, which at the bottom of the fall consists of boulders of limestone. The passages which have been explored are all at a considerable elevation above the floor of the large chamber, and must thus belong to an earlier period in the history of the cave.

It is impossible to obtain access to the present further course of the water owing to the accumulation of boulders at the bottom of the cavern.

It has been surmised that the bottom of the large cavern consists of Silurian or Ordovician rocks, but as the solid floor is nowhere visible there is no direct evidence, and the fact that the water passes away through the floor of the chamber proves that the bottom of the limestone is not reached, as the older rocks are impervious.

Here then the work of the Committee was commenced on April 27th and 28th, 1900.

On Saturday, April 28th, specimens of water were taken from Clapham Beck and from several important springs in and around Clapdale, with the object of ascertaining the normal composition of the water prior to the introduction of the test materials with the following results.

Results of analysis by Mr. Wm. Ackroyd, of samples of water collected on April 28th.

Name of Spring.	Cl. parts per 100,000.
Moses Well (S 7)	1·37
Eldon Hall	1·27
Long Kin East (P 8)	1·47
Clapham Beck Head (S 12)	1·35
Gaping Ghyll (P 3)	1·20
Average	1·33

A gauge board was erected across the Fell Beck just above the point where the water commences to sink. This gauge had a notch 1 foot wide, and at the time of the experiment now to be described the flow was $3\frac{1}{4}$ inches, being equivalent to 251,856 gallons per 24 hours. The stream, however, was entirely absorbed by the limestone before the main entrance to Gaping Ghyll was reached, and no water was falling down the main shaft.

Subsequent investigations* have shown that the water sinking in the cracks about 200 feet up Fell Beck from the mouth of Gaping Ghyll and between these two points flows into the cave at the foot of the main hole by way of the parallel shaft and the underground waterfall already mentioned.

Thus the water which sinks in the bed of the beck, and that which in wet weather flows over the lip of the main hole, have a common destination, since they mingle at the foot of the shaft. This knowledge simplifies matters considerably, as it is rendered unnecessary to test the stream under varying conditions of rainfall.

Two charges of ammonium sulphate, each consisting of 2 cwt., were put into the dam above the gauge board at 11.30 a.m. and 2.30 p.m. respectively on April 28th, 1900, the quantities used being comparatively small on account of the fact that all the springs in Clapdale flow into Clapham Lake, which is used as a public water supply, and it was therefore necessary to avoid the introduction of larger quantities.

From the time of the introduction of ammonium sulphate, samples were collected from Moses' Well (S 7), from a small spring (S 13) just above Clapham Beck Head, from Clapdale Sike (S 10), and from Clapham Beck Head (S 12), the large spring issuing from the foot of the western wall of the gorge just above the bridge at the entrance to Ingleborough Cave (Pl. XXXII., Fig. 2).

Only small traces of ammonia were found in the three first-mentioned springs, but on the morning of May 3rd a fair amount was detected in S 12; by noon of the same day this

* S. W. Cuttriss, Yorkshire Ramblers' Club Journal, Vol. II., No. 5, 1903, pp. 48-51.

DIAGRAM SHOWING CHLORINE (PARTS PER 100,000) AT CLAPHAM BECK HEAD (S 12).

had increased very considerably, but there was a considerable diminution in the evening. From this date until May 6th ammonia was present in diminishing quantity, and on the evening of that day only a trace remained.

This result fully proved the direct connection of Gaping Ghyll with the spring at Clapham Beck Head. The water took five clear days to pass along its underground course over the mile that intervenes between these points.

There being some doubt as to whether any of the other springs were affected by the ammonium sulphate put into Gaping Ghyll, it was decided to perform another test with common salt, as the quantity of this substance in the waters of the springs was not so liable to be affected by natural causes.

Accordingly half a ton of salt was introduced into the waters of Gaping Ghyll on June 4th, 1900, and another half ton on June 5th, samples of water being taken from all the important springs in Clapdale several times a day until June 25th.

The salt from Gaping Ghyll appeared at Clapham Beck Head on June 15th, 16th, 17th, 18th, 19th, 20th, 21st, being at its maximum on June 18th, thus taking eleven days for its first appearance and fourteen days to attain a maximum [Pl. XXV.].

The difference in time taken by the tests in the April and June experiments to travel from Gaping Ghyll to Clapham Beck Head is of interest. Unfortunately there is no rain gauge at Clapham, but by the kindness of Mr. Walter Morrison, of Malham Tarn, Mr. Thos. Coulthard has supplied the register of rainfall at that place for the months of April, May, and June, 1900. This shows that there was a decidedly heavier rainfall in April than in May, that for April being 3·88 inches, whilst from May 4th to June 4th only 2·09 inches fell. It would appear therefore that the time of flow is much longer after a period of diminished rainfall.

None of the other springs were affected in the slightest degree, proving that the small increases in the quantity of ammonia carried by these minor streams during the previous experiments were not due to the ammonium sulphate introduced at Gaping Ghyll.

As one of these streams receives the drainage from a farm-yard, and the other was at the time nearly dry and flowing through pasture-land, the irregularity in the quantity of ammonia is not to be wondered at.

With regard to the actual route taken by the water, nothing very definite is known, but it seems probable that it follows the direction of the underground passages leading from the Cavern of Gaping Ghyll, which have been explored and surveyed by members of the Yorkshire Ramblers' Club* [Fig. 4 and Pl. XXIV.], and passes through the inner portion of Ingleborough Cave by way of certain passages lying between the Giant's Hall and the deep gorge of Trow Gill (Pl. XXXI.).

Full accounts of Ingleborough, or Clapham Cave, as it is more frequently called, will be found in the Ramblers' Club Journal.†

At 10 p.m. on June 8th, 1 lb. of fluorescein was introduced into the stream flowing through Ingleborough Cave, at the point where the water plunges down a hole in the floor of the cave, and marked "Abyss" on the 6 inch Ordnance Map.

This appeared at Clapham Beck Head (S 12); and it was thought also at Moses Well (S 7), but subsequent investigations have shown that the waters of this spring have a different origin.

P 4 is a dry pot-hole, blocked by fallen débris.

Eastward of Gaping Ghyll, in the angle between the two walls at the head of Clapdale, is a deep depression (P 5) with signs of a stream course at the bottom. This is usually dry and has consequently not been tested.

Sinks on The Allotment.

P 6 Marble Pot has practically no stream and the same is the case with Jockey Hole and an opening immediately to the south of it, which has been recently explored to a depth of 320 feet by several members of the Ramblers' Club, and will

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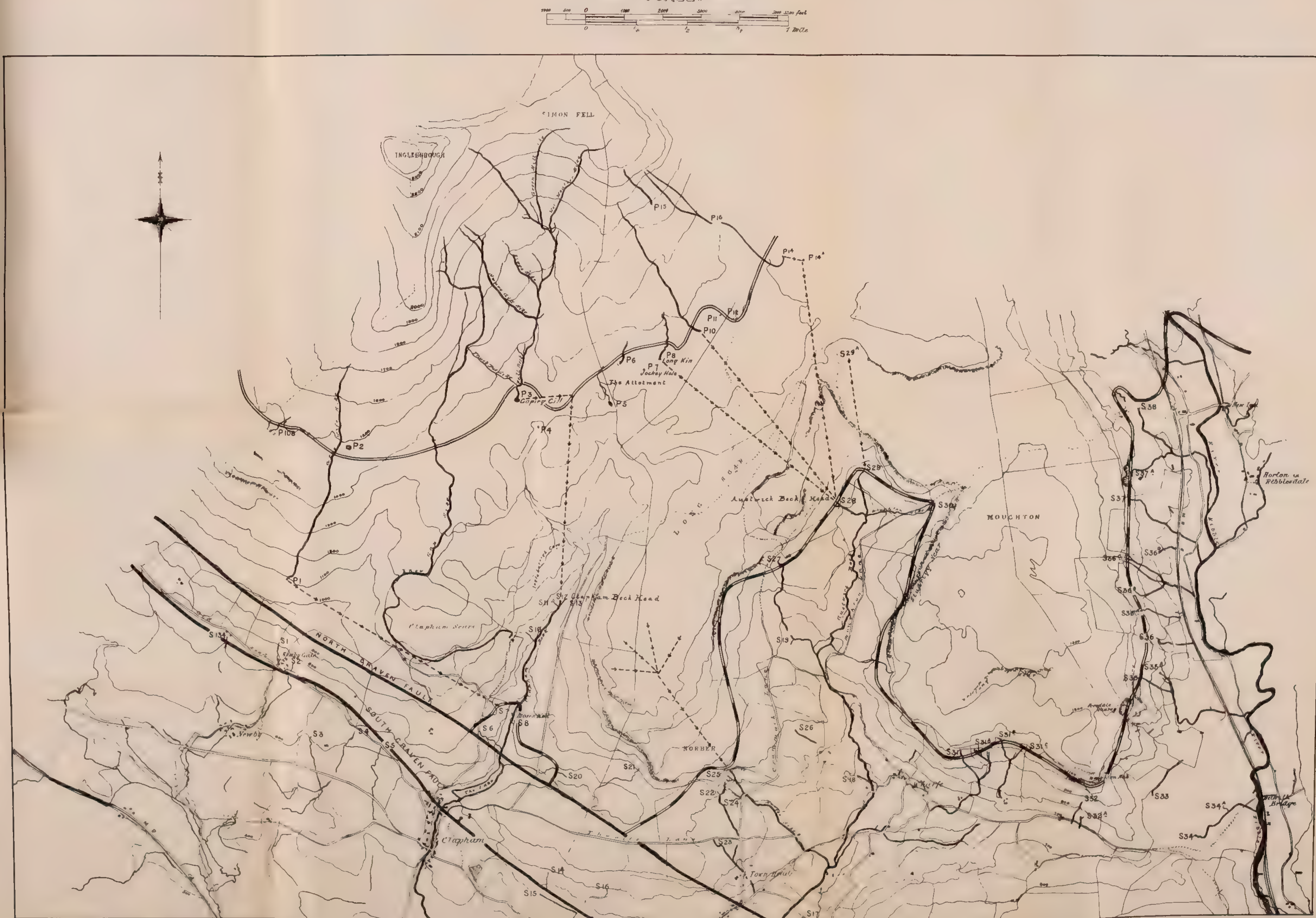
* Yorkshire Ramblers' Club Journal, Vol. I., pp. 65-123.

† Yorkshire Ramblers' Club Journal, Vol. I., pp. 220-228.
,, ,, ,, ,, Vol. II., pp. 52-63.

UNDERGROUND WATERS OF N.W. YORKSHIRE.

SOUTHERN AREA.

SCALE.



Upper boundary of Carboniferous Limestone — Lower boundary of Carboniferous Limestone — Faults — Direction of Underground Flow.

Reproduced from the Ordnance Survey Map with the sanction of the Controller of H.M. Stationery Office.

shortly be described in the Journal of that Society. These were not tested on account of their being dry.

Long Kin East (P 8) is a long rift in the limestone, some 12 feet in depth, at the bottom of which a stream flows in a series of cascades, and passes at its lower extremity into a cave.

Here $1\frac{1}{2}$ lbs. of fluorescein in alkaline solution were introduced at 1.20 p.m., on April 28th, 1900.

The most prominent joints in the limestone at Long Kin run in a N.W. to S.E. direction. This line if continued passes near the large springs at Austwick Beck Head (S 28) [Pl. XXXIX., Fig. 1], and it was therefore determined to watch the springs in that neighbourhood as well as those in Clapdale.

The springs in Crummack Dale which unite to form Austwick Beck were watched by Mr. T. R. Clapham, F.R.A.S., of Austwick Hall, and Mr. Harry Harrison, of Clapham. Reports received from these observers show that they did not notice any fluorescence in the streams from April 28th to May 10th. On May 11th, Mr. Harrison, accompanied by Mr. E. Spence, visited the springs at Austwick Beck Head (Ordnance Survey 6 inch map) (S 28) at 8.30 a.m., and found the water distinctly coloured. On the same day, Mr. Clapham reported the water at Wharfe Bridge distinctly tinted, and the fluorescence was found to increase in vividness as the stream was followed towards Austwick Beck Head. The fluorescence continued to be observed for several days. Mr. Clapham also examined the springs at Nappa Scar (S 22–24 and 25) at the south-east corner of Norber, and Mr. Harrison visited the springs at (S 27) Crummack Farm and Capple Bank Wood (S 29), but no fluorescence was observed. The weather being dry, no water was flowing along Moughton Sike. These interesting results reveal a direct connection between Long Kin East and Austwick Beck Head. The delay in the appearance of the fluorescein (ten days) was probably due in part to the small amount of water flowing into Long Kin East at the time of the experiments.

A reference to the contoured maps, Pls. XXII. and XXVI., will show that Gaping Ghyll and Long Kin are both in the catchment basin of Clapham Beck, but notwithstanding this fact, the waters of Long Kin pass beneath the surface watershed into the Crummack valley. This is doubtless partly due to the direction of the master joints in the limestone, but is probably also due to the presence of a subterranean ridge of impervious rocks of Silurian and Ordovician age which runs across Crummack Dale in an E.S.E. and W.N.W. direction and which if continuous would pass between Gaping Ghyll and Long Kin East.

The exact conformation of this ridge beneath the limestone will be better understood by reference to Pls. XXVI. and XL., and Fig. 3 (p. 256).

Five cwt. of ammonium sulphate was introduced into a sink on The Allotment (P 10). about 500 yards N.E. of Long Kin East, on June 9th. at 3 p.m.. and this reappeared at Austwick Beck Head on June 22nd. having taken 13 days to accomplish the journey. None of the other streams were affected on that day, but on the 24th and 25th two small streams in Clapdale which had previously shown irregularity (see pp. 265-6) as regards their ammonia percentage were again slightly variable, but for reasons previously explained no importance was attached to this.

P 11 and P 12 on The Allotment are usually dry. and have not been tested, but from the results obtained at the Shooting Box Stream immediately to the north it is obvious that their waters must flow to Austwick Beck Head (S 28).

A stream which rises on the southern slope of Simon Fell [Pl. XXVII.] sinks at P 16. passes through a thin limestone, re-emerges at S 37, and flows past the Shooting Box on The Allotment.

On June 9th of the same year 1 lb. of fluorescein was poured into the stream which flows past the Shooting Box and then passes through the wall and sinks at the extreme southern end of Fell Close (P 14) near the Bench Mark 1320.1 (6 inch Ordnance Map).

Of this no trace was found. and consequently the experiment was repeated on June 26th. 1903, when 2 lbs. of fluorescein were put in.

All the springs from Austwick Beck Head to Turn Dub were watched for a period of ten days by members of the

Committee, and also by residents in the neighbourhood up to the time of the next meeting, but without result.

On the day following the introduction of the test there was a very heavy flood, which may account for the non-success of the experiment, fluorescein when dilute being very difficult to detect in the brown peaty water of these streams except in brilliant sunshine.

This problem was again attacked in 1904, when 4 lbs. of fluorescein were introduced at P 14, the stream being then in moderate flood. During the night heavy rain fell, and on the following morning the spring at Austwick Beck Head (S 28) was very strongly coloured.

This is an interesting case, inasmuch as the stream which flows past the Shooting Box runs in a depression in the side of Ribblesdale, and would if it continued its course on the surface inevitably fall into the River Ribble.

It passes, however, by way of the pot hole P 14a, and then apparently falls into joints at right angles to its previous direction, flows southward, passes under the watershed and emerges at Austwick Beck Head, whence it passes by way of Austwick Beck and the River Wenning into the Lune, while its neighbour to the north (P 18 and 19) flows into the Ribble. Thus, owing to the engulphment of one of them in the limestone, these two streams, separated only about 200 yards from each other, and which would under normal conditions flow into the same river (the Ribble), reach the sea at points separated by a distance of some 25 miles.

The Underground Drainage of Norber and Moughton.

On reference to Pl. XXIII. it will be seen that these two hills are spurs of the limestone plateau, on which Ingleborough stands, which run out for a considerable distance in a southerly direction from the main mass. The former separates Clapdale from Crummack Dale, while the latter lies between Crummack Dale and Ribblesdale. They both terminate at a short distance to the north of the Inner Craven Fault, to which, and the subsequent denudation, they owe their existence.

In the case of Ingleborough the impervious shales of the Yoredale Series give rise to surface streams which, as already described, flow on to the limestone plateau and are swallowed by the various pot-holes.

On Norber and Moughton, however, the limestone plateau has no such covering of shales, with the result that no surface streams are formed, the rain being absorbed as it falls by the joints in the limestone.

Under these circumstances it is of course impossible to trace the lines of flow of the underground waters which must, however, collect into somewhat definite channels, as there are many powerful springs round the base of both these hills. These springs are thrown out at or immediately above the line of junction of the limestone with the underlying impervious rocks, and the direction of underground flow will doubtless be controlled by the irregularities in the surface of the latter.

Thus in the case of Norber [Pls. XXII. and XXVI.] the springs S 20, S 21, S 22, S 23, S 24, S 25 and S 26 lying to the south of the Silurian ridge were unaffected by reagents introduced into the various pot-holes to the north of that ridge, and therefore probably receive their supply from the general surface soakage on the bare limestone "clints" which form the summit of the hill.

Again, in the case of Moughton a small spring, S 29a, on Thieves Moss, which rises at the foot of the upper escarpment and almost immediately sinks again, reappears as the small spring at Capple Bank Wood S 29, but to the south of that point not one of the springs was affected by the reagents introduced on the main plateau.

Moughton, therefore, like Norber, possesses an underground drainage quite independent of that of the main plateau, but the absence of surface streams and of definite water sinks again prevented the application of tests.

The portion of Moughton to the north of the Silurian ridge is drained by Moughton Sike S 30 on the west, and by S 35, S 35a, S 36, S 36a, S 36b, S 36c, S 36d, S 37, S 37a and S 38, most of which are wet weather springs only, running dry in fine weather, on the east; while the portion to the south of the ridge discharges its waters by way of S 31, S 31a, S 31b, S 31c, S 32, S 32a and S 33. (S 34 and S 34a are small streams rising in the peat bog known as Swarth Moor.)

The Sinks in the neighbourhood of Alum Pot. [Pls. XXII., XXVII., and XXIX.]

Fell Close Sike rises on the steep slopes of Simon Fell and flows in an E.S.E. direction until it sinks at P 18 into a thin limestone of the Yoredale Series. Fluorescein introduced at P 18 reappeared a short distance below and again sank at P 19, this time into the Mountain Limestone. From this point onwards the joints in the limestone carry the water in a northerly direction almost at right angles to the slope of the ground, across a series of "clints" and to S 51 [Pl. XLI., Fig. 2], where it again comes to light. At this point it is joined by a stronger flow of water from P 25 and P 26, which will next be described, together with the further course of the water from S 51.

P 25 receives a stream which is very puny even in wet weather and passes on to P 43a.

P 26 receives a much more important stream, which on entering the limestone falls into the joint line and runs parallel to the water from P 19—reappearing at P 43a. The line of joint is well marked, both by crevices in the clints and by a line of pot-holes, in some of which the water shows itself. It runs N. 18° W.

At P 43a the water falls into another open joint, running N. 25° E., which leads it to S 51.

From S 51 the water flows through a shallow open channel in the limestone, sinks at P 43, and again emerges partly from a small cave at S 40 and partly from a spring at S 40a, almost immediately sinks again and comes to the surface at two adjacent springs S 42. From S 42 the stream flows over a pasture, passes through a wall, crosses the corner of a second pasture, then under another wall into a third field. After passing through the second wall, the stream is partly absorbed into the limestone at P 37a (in dry weather it is entirely absorbed) and finally disappears at P 37 close to an old limekiln.

In extremely wet weather the stream flows on over the surface past Gill Garth and joins the water from S 47 (Gillgarth Beck).

The water sinking at both P 37 and P 37a again experiences the effect of the strong N. and S. jointing of the limestone and is carried at right angles to the slope of the ground to P 38, where, after an open course of about three yards, it again disappears, to emerge at two springs S 43 and S 44. A few yards below S 44, a small tributary comes in from S 52a, which was not affected by any of the tests and which therefore probably owes its existence to general surface drainage. The stream then flows on by P 39, where it again sinks, to Font Green Spring S 45. After passing through the wall, a portion of the stream again sinks at P 40 (the whole in seasons of drought) and emerges at S 46. From this point onwards it flows over the surface, forming Selside Beck, a tributary of the River Ribble.

The next series of streams is one of the most interesting in the district, offering as it does a large number of problems for solution.

A number of streams, rising in the angle between Simon Fell and Park Fell, converge upon a line joining Alum Pot with Selside Village, and although they must flow very near to the series last described are not in any way connected with it, being at a lower level.

Alum Pot Beck is formed by the confluence of a large number of small streams, chief among which is South House Moor Beck.

On the 6 inch Ordnance Map, Alum Pot Beck is shown as flowing over the lip of Alum Pot, but as a matter of fact this very rarely occurs, although there is a well-marked dry channel connecting the upper part of the Beck with the pot.

In ordinary weather the whole of the waters of Alum Pot Beck sink at P 33, while the water from S 58, a small spring quite unconnected with the main flow, supplies the stream which flows over the lip of Alum Pot.

UNDERGROUND WATERS OF N.W. YORKSHIRE.

ALUM POT AREA.

SCALE.

Upper boundary of Carboniferous Limestone. Lower boundary of Carboniferous Limestone. Direction of Underground Flow.

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

The water from P 33 again comes to light at S 57, where it is joined by the waters of Long Churn Spring, which sink at P 42, about 100 yards to the west of S 57.

The water from S 57 flows through a small gorge over a series of cascades and enters a cave at P 31. [Pl. XXXIII., Fig. 1.] This cave is the upper portion of a series of passages and chambers known by the general name of Long Churn, which has been carefully surveyed by members of the Committee with the aid of Mr. Theodore Ashley. [Pl. XXVIII.]

These passages are excavated in the upper portion of the Mountain Limestone, and are at no great depth from the surface. On entering at P 31 the cave is sufficiently high for a man to stand upright and a few yards from the entrance it divides into two, the one to the left being that followed by the water, the passage to the right being an "ox-bow" deserted by the stream except when in flood. About 50 feet below the point of reunion of the two branches, the stream plunges down a waterfall some 15 feet in height into a chamber measuring, roughly, 50 by 20 feet, the greatest dimension being at right angles to the general direction of the passage. The greater part of the floor of this chamber is occupied by a pool, from which the stream flows on in an easterly direction. At first the passage is low and one must walk in a stooping posture, and though narrow at the bottom it widens considerably towards the top. As we proceed the tunnel becomes more lofty, as the roof, which is formed by a massive bed of limestone, remains horizontal, but the floor gradually falls away. For the next 600 feet the character of the passage varies but little. There are, however, a few pools, varying from one to three feet in depth, and a number of deserted ox-bows, some of which are at a height of five or six feet above the bed of the stream.

At the end of this 600-foot reach a small passage branches off to the right. This is some four feet above the water level and eventually rejoins the main passage lower down, though it becomes so low that it is not possible to get through.

From this point the water flows for another 100 feet or so when the passage again bifurcates, the water in this case taking the right-hand passage, while that to the left comes out to daylight at P 30.

This passage is an underground ox-bow, a portion of the roof of which (at P 30) has fallen in.

At P 30 a small stream from S 55 flows in, the origin of which will shortly be described.

On entering the cave on the lower side of P 30 and turning sharply to the right [Pl. XXXIII., Fig. 2], we again encounter the water from the upper part of the passage, which has taken a shorter route and joins the passage which we have traversed by a waterfall some 12 feet in height. Below the fall the passage is nearly straight for some distance and then again turns sharply to the right, where the water enters a pool much encumbered with boulders. Here the water passes out of the cave by a low tunnel, through which daylight can be seen, and comes to the surface at Dickon Pot P 27, where it passes into a second cave. In order to explore this it was necessary to erect a wooden dam at the point marked X on Pl. XXVIII., which had the effect of turning the bulk of the water down an old high level course, which will shortly be described.

From P 27 the water flows over a series of cascades, with a deep pool at the foot of each, and finally plunges down an underground shaft or pot hole which has not yet been fully explored.

Fluorescein was introduced here during a descent of Alum Pot by members of the Ramblers' Club, and it was found that the water entered the cave at the bottom of Alum Pot, some 250 feet below, by way of a waterfall through the roof.

The passage which took the water when the sluice in the dam X was closed, passes over a series of steep pitches, with a deep pool at the foot of each, and eventually opens into the side of Alum Pot at a depth of 80 feet from the surface.

Thus it will be seen that the waters of Long Churn pass into Alum Pot, whether they go by way of Dickon Pot or the older and higher level channel below the dam.

The two channels are connected, at a point about 100 feet beyond the entrance to Dickon Pot, by an extremely low passage, known to those who frequent the place as "The Creep," and as

The arrows indicate the course of the stream.

SCALE.

0 10 20 30 40 50 60 70 80 90 100 150 200 FEET.

PLAN OF LONG CHURN.

roc Yorks. Geol. and Polytec. Soc., Vol. XV., Plate XXVIII.

for some distance it is only 18 inches in height it fully justifies its name.

Whit-a-Green Spring rises on the higher slopes of Park Fell (a spur of Simon Fell), at a height of 1,600 feet, and flows over the surface of the Yoredale Rocks till it reaches the Mountain Limestone at 1,250 feet, where it sinks at P 29.

A trial with fluorescein resulted in proving that this water flows out at S 55 and joins the Long Churn System at P 30.

The channel by which the stream flows from P 29 to S 55 can be traced for a considerable distance by means of a series of openings to the surface, and the passages were actually traversed throughout almost their entire length, although in many places the water was three feet deep. The exploring party was eventually stopped by the roof coming down to the water level.

In the same enclosure is a small spring marked S 53, which never yields much water and is quite dry in seasons of drought. The water of this spring is derived from the drainage of a peat bog, which owes its existence to a patch of glacial drift resting on the limestone.

The water sinks at P 28 and issues, as proved by a fluorescein test, at S 55, along with that from P 29.

The underground junction of these two streams was afterwards traced, though it was found to be impossible to follow the whole length of the passage, the roof being too low, and there being deep pools of water lying in the bottom.

It may be mentioned in passing, that as this was a short run, methylene blue was first tried for the test ; but although only a small quantity of water was flowing at the time, the colour was not seen at S 55, while one-fourth the quantity of fluorescein succeeded two hours later under precisely similar conditions.

This concludes the investigation of the streams flowing into the passage at the bottom of Alum Pot, and the further course of the water from the bottom of that chasm will now be described.

Alum Pot is a huge rift in the limestone (Pl. XXXIV.) which descends vertically to a depth of some 200 feet, and is

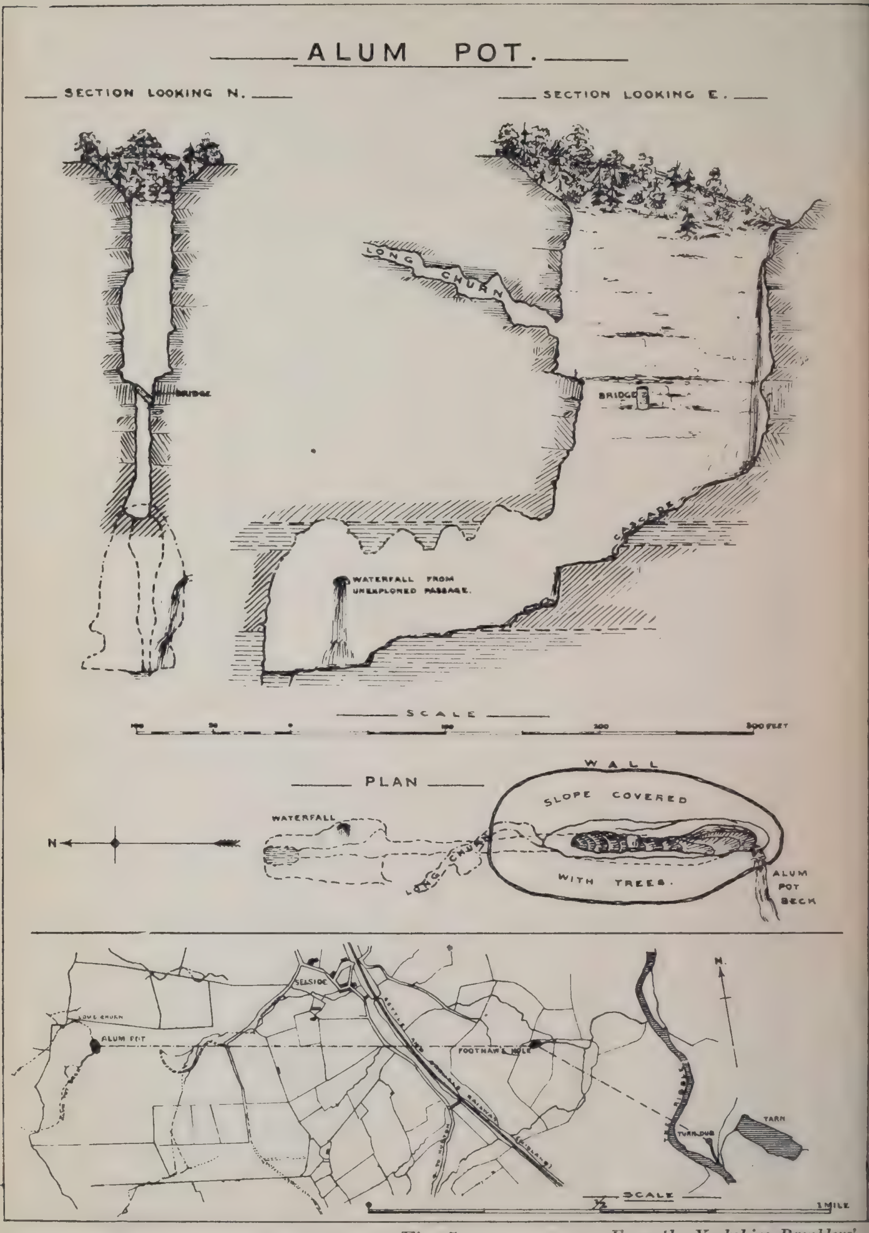
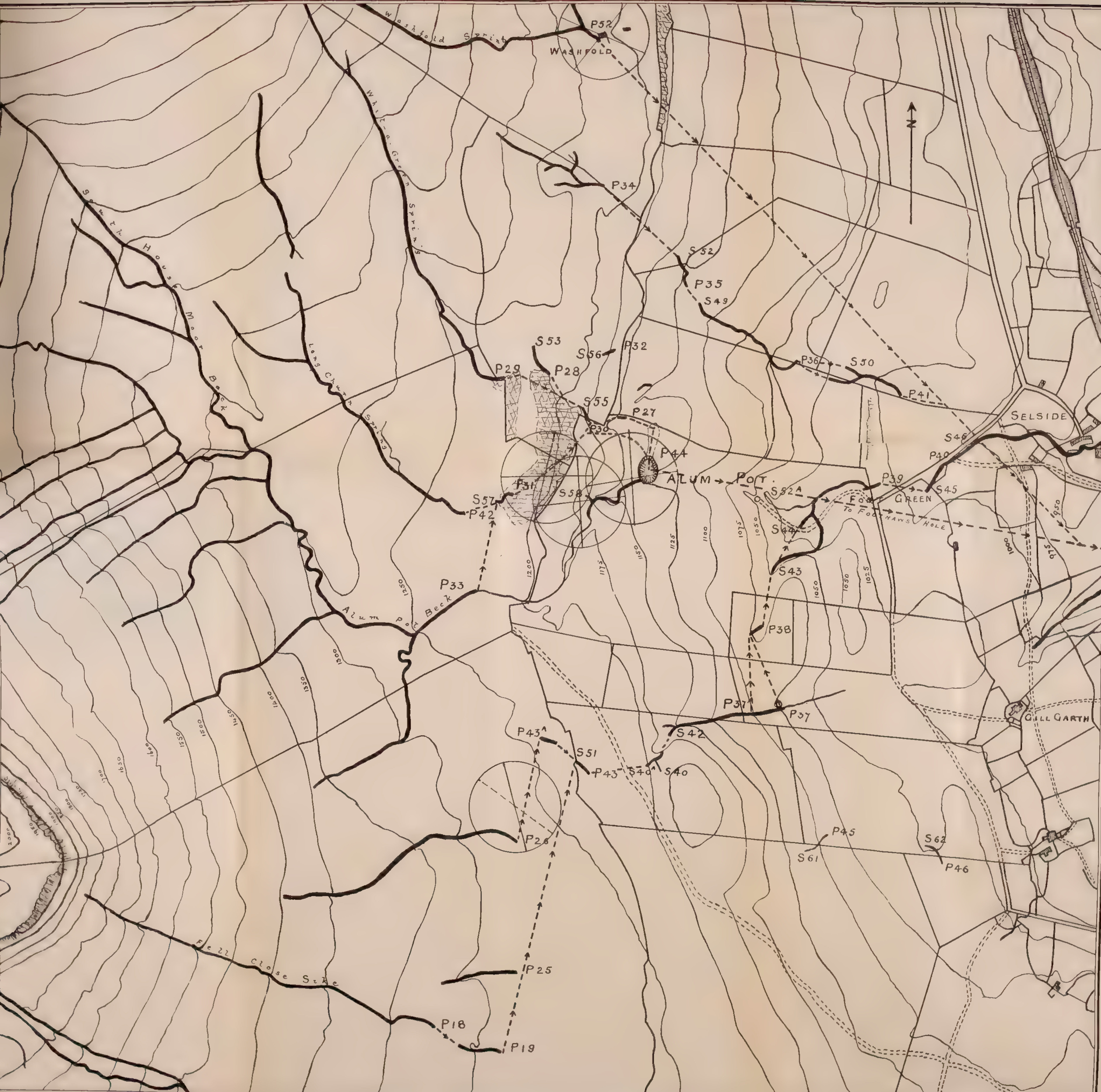


Fig. 5.

From the Yorkshire Ramblers' Club Journal, by permission.



Proc. Yorks. Geol. and Polytec. Soc. Vol. XV Plate XXIX

ENLARGED PLAN OF ALUM POT AREA.

SCALE 12 INCHES. TO 1 MILE.

– – – → – – – – DIRECTION OF UNDERGROUND FLOW

DIRECTION OF JOINTS.

then continued by a series of sloping passages and chambers to a depth of 290 feet, at which level the water stands up to the roof, barring further progress* (Fig. 5).

The joints in the neighbourhood of Alum Pot are more complicated than in the parts of the district previously investigated, there being three sets of joints, all more or less irregular in places.

Close to Alum Pot there are two sets running S. 5° W. and N. 80° E. respectively.

Thirty yards higher up Alum Pot Beck they run due N. and S. and N. 80° E., the north and south joints being the stronger and more continuous.

On the "clints," 100 yards above the Pot, there are three sets of joints, as follows, viz. :—

Master	N. 10° E.
Secondary	N. 35° E. N. 85° E.

At 4 p.m. on September 5th, 1901, three quarters of a pound of fluorescein was put into the water flowing down Long Churn (which has already been shown to communicate with Alum Pot) and a similar quantity at 5.30 p.m. on the same day.

On September 17th, the water of a large spring, Turn Dub (S 67) (Pls. XXII. and XXVII., and XXXV., Fig. 2), on the opposite side of the River Ribble, was strongly coloured, the fluorescein having been observed on the previous day in the pool at the bottom of Footnaw's Hole (S 65) [Pl. XXXV., Fig. 1]. Twelve days were thus required to accomplish the journey of 1½ miles from Alum Pot to Turn Dub.

The relative positions of Long Churn, Alum Pot, Footnaw's Hole, and Turn Dub will be seen by reference to Pl. XXVII.

The top of Alum Pot is 1,125 feet above the sea, and at the furthest point reached, viz., at a depth of about 290 feet from the surface, or at 835 feet above the sea, the water completely fills the passage, which gradually slopes below its surface. Now the lip of Footnaw's Hole is just below the 825-foot contour,

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* A full description of Alum Pot will be found in the Yorkshire Ramblers' Club Journal, vol. ii., No. 5, pp. 35-47.

and the water level in ordinary weather 25 feet lower. It will therefore be seen that the water at the bottom of Alum Pot is approximately on the same level as that in Footnaw's Hole and also in Turn Dub. Since the water is in motion through this underground passage, which must be constantly filled, the friction will probably be sufficient to account for the small difference of level.

In dry weather Footnaw's Hole (Pl. XXXV., Fig. 1) appears as a wide cleft in the limestone, with sloping banks of silt and sand round two sides, and precipitous limestone rocks on the other two. When the streams are in flood after heavy rain, or during the melting of snow, the water in Footnaw's Hole rises to the lip and flows over down Footnaw's Beck into the Ribble.

Turn Dub is rarely, if ever, dry, while it is only in exceptionally wet weather that water flows from Footnaw's Hole.

Thus it would appear that Footnaw's Hole is a flood outlet, and only comes into operation when the underground passage leading to Turn Dub is full and, therefore, unable to take the excess of water. As the lip of Footnaw's Hole is just below the 825-foot contour, and Turn Dub just below that of 800 feet, there cannot be a fall of more than 25 feet from the former to the latter.

Further, since in ordinary weather, when the stream is issuing from Turn Dub only, the water in Footnaw's Hole stands some 20 feet below the ground level, it will be seen that there must be a syphon-like passage below the river; and since this passage must be constantly filled with water up to the level of the overflow of Turn Dub, it will account for the very slow passage of the fluorescein over at least this part of the journey.

Since the water passes beneath the River Ribble it follows that there must be some impervious cover, because if this were not the case the water of the underground stream would find an escape at the lowest point, namely, in the bed of the river, and would not, as is the actual case, pass under that stream and rise some 10 or 12 feet above it on the opposite bank.

With a view to ascertaining the nature of this impervious cover and its thickness, it was determined to carry out a series of boring operations in the alluvial flat between Turn Dub and the river, the owner of the land, Mr. J. Hammond, having kindly given his permission.

In the first place Turn Dub was sounded and found to be only about 18 feet in depth. Now Turn Dub is a circular pond of still water, and although a large stream flows out there is no disturbance of the surface, no welling up of the water apparent. This would lead one to suppose that the pool was much deeper than is actually the case. So far as could be ascertained by drawing the sounding-iron across the pool, the bottom consists of large boulders. This led the Committee to suspect that the cover was boulder-clay, and that the bottom of Turn Dub consisted of boulders, the clayey matrix having been removed by the action of the flowing water.

The boring operations were undertaken with a small set of hand boring-rods provided with an auger bit.

With this apparatus it was possible to prove that the bluish alluvial clay was underlain by a material consisting of a somewhat sandy brown clay with many large stones, in every way similar to the boulder-clay of the neighbourhood, which in some places can be seen close to the river bank.

The presence of numerous boulders prevented the boring operations being carried more than one or two inches into the boulder-clay, so that it was impossible to obtain any definite evidence regarding the thickness of the bed.

Further, although boulder-clay was proved to underlie the alluvium on both banks of the Ribble it was impossible to obtain evidence of its existence in the river bed, as this consists of coarse shingle which could not be penetrated by the light hand-boring apparatus employed.

In order to clear up this matter satisfactorily the services of a professional well-sinker were engaged, with the result that the existence of boulder-clay below the bed of the river was conclusively proved.

In all seven bore holes were put down, but owing to the extremely stony nature of the ground only one of these reached the bed-rock.

This was on the right bank and some 20 feet from the river, and the limestone was reached at a depth of eight feet below

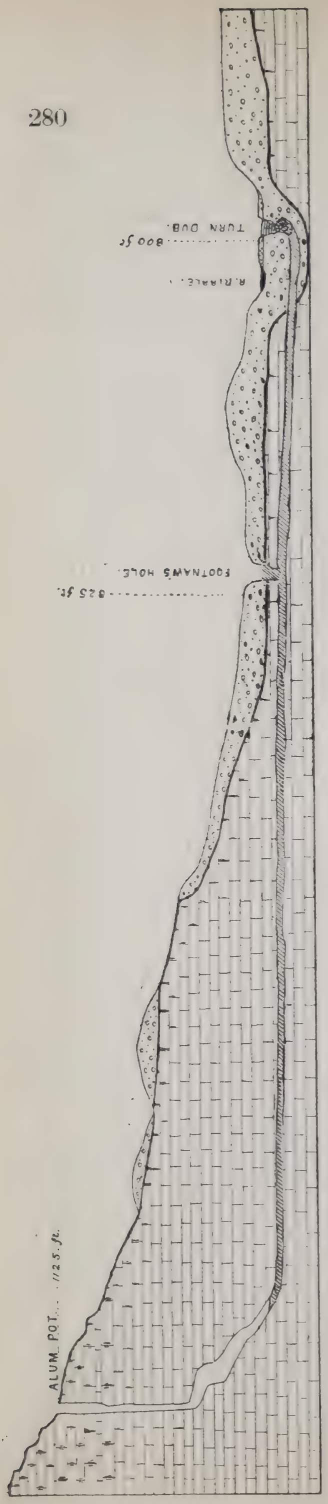


Fig. 6.

SECTION FROM ALUM POT TO TURN DUB.

the level of the river bed. In another case a little further from the river bank a bore hole reached a depth of 14 feet when it became blocked by a boulder, the whole of this bore hole being in boulder-clay, the limestone floor not being reached. The Ribble can be seen to be flowing over drift, no solid rock being exposed for nearly two miles above Turn Dub or 300 yards below it.

As has been shown, the water in Alum Pot is nearly on the same level as that at Turn Dub, while the two are connected by a passage constantly filled with water and at a lower level than the outlet (see Fig. 6).

It is difficult to see by what means such a passage could be eroded unless there was formerly an outlet at a lower level than the present one.

Since the present bed of the river is excavated in boulder-clay it follows that the pre-glacial bed must be at a lower level than the present one, but has not yet been cleared of glacial drift.

In this older and deeper valley, then, was the original outlet of the waters of Alum Pot. This outlet was during the glacial period completely stopped up with boulder-clay so that when the flow of water was resumed it had to force a new passage through the boulder-clay, viz., Turn Dub, which happened to be on the opposite side of the present river course. The pressure necessary to re-open the passage is not far to seek, since if Footnaw's Hole and Turn Dub were stopped up the water in Alum Pot would rise to the surface, giving a 300-foot head of water.

This series of observations is of particular interest, since if the above is the correct explanation it proves that Alum Pot and possibly also Long Churn are of pre-glacial origin.

A series of small springs rises beneath the drift and peat near the wall at the north end of Whit-a-Green. These run together and form a small stream which sinks at P 34, a small pot hole amongst long grass. Fluorescein was introduced here and reappeared in half an hour at a small opening some 100 yards to the south of P 34: here the stream can be traced on the surface for 20 yards, when it again sinks.

The fluorescein was put into P 34 at 4 p.m. and was traced the following day at S 52; then overground to P 35, where it again sank, to reappear at S 49; thence it flowed to P 36, and so underground to S 50, finally sinking at P 41.

The fluorescein sinking at P 41 did not affect any of the springs on Font Green, but was again seen in Footnaw's Hole.

This water must, therefore, go by a deep course, and eventually join the underground flow from Alum Pot to Turn Dub, *viâ* Footnaw's Hole.

Passing northwards the next water sink encountered is that at the Washfold (P 52), on Bent Hill Rig, Park Fell. This receives the waters of Washfold Spring and Old Fold Spring, the latter having been diverted to this point.

Here half a pound of fluorescein was put into the sink at 2.15 p.m. on April 4th, 1903.

This had almost disappeared at 6.15 p.m, when a second half-pound was introduced, being arranged so as to flow in slowly and keep up the supply for a considerable time. The stream was still coloured on April 5th, at 1.30 p.m., when the remainder of the charge was sent down in a flush. The stream was slowly dwindling on the 5th, it having been in flood on the previous day.

All the springs in the neighbourhood were carefully watched for several days, but no result was observed.

Consequently this experiment was repeated and it was eventually found that the fluorescein reappeared at Footnaw's Hole, having, like the water from P 41, joined the deep-seated flow from Alum Pot to Turn Dub.

P 51 was quite dry owing to the diversion of Old Fold Spring previously mentioned.

This was the last stream in passing northwards found to communicate with Turn Dub.

The above streams from P 19 on the south to P 34 on the north, occupy a wide valley and would, with the exception of Gill Garth Beck (S 42 to P 37), all drain into Selside Beck were they not swallowed into cracks in the limestone.

There would appear to be two distinct sets of channels below Font Green—a deeper and a more superficial one.

The water flowing by the deeper channels, viz., that from Alum Pot, Long Churn, P 41 and P 52, reaches the Ribble by way of Footnaw's Hole and Turn Dub, while the shallower set issues at the lower end of Font Green and joins Selside Beck.

The deeper set has been shown to be of pre-glacial origin (p. 281), and it seems highly probable that the shallower set is of recent date. The channels are not so well marked as in the case of the deeper set. The streams which flow in the shallower set of channels might in some instances flow into Alum Pot if they continued on the surface, but when captured by the joints they are carried down the hillside to emerge on the slope below the mouth of that opening, and consequently could not enter the lower set of passages unless another deep chasm existed, connecting these with the surface.

P 50 is a small pot-hole on Bent Hill Rig. It is usually dry and consequently has not been tested.

There are several small springs in the pastures between Bent Hill Rig and the River Ribble (viz., S 75, S 76, S 77, S 78, S 80, S 81, S 82. and S 83) which have not been affected by any of the tests introduced, and which we consequently attribute to the general drainage of the clints.

Two large springs at the bend of the Ribble, S 84 and S 85, have likewise been unaffected.

Streams near Colt Park Farm.

The streams sinking at P 62, P 63, and P 64, near High Barn, were found to unite in the spring at S 89 and to flow overground to Colt Park Farm, where the water sank, to reappear at S 90, whence it flowed overground for a few yards and again sank. This water was again seen in the spring S 93, in Salt Lake Quarry, where it forms a waterfall visible from the railway. It then crosses beneath the railway and sinks in a mass of glacial gravel at P 65, below which point we were unable to trace its course.

The fluorescein from the flows just described having been allowed to pass off, the streams sinking at P 48 and P 49, near Bent Hill Rig Barn, were next tested. These were found to unite and to flow along a master joint in the limestone, *viâ* P 59 and P 60, and then to turn down a cross joint to S 88, on Ashes Shaw Pasture Rocks. From S 88, after an overground journey of about ten yards, the water sinks at P 61, and again resumes the direction of the master joints running parallel to the hillside to Rake Spring, S 91.

The stream from Rake Spring flows overground past the south end of Salt Lake Quarry, beneath the railway, and through Ashes Gill Plantation to P 66, on Ashes Eller Bank, where it sinks in glacial gravel near the river.

Streams near Ribblehead Station.

S 102 is a small spring issuing from the grit beds of the Yoredale Series, above Keld Bank, on Park Fell. The stream from this spring sinks at P 73, about half a mile south-west of the station, at a height of 1,240 feet above the sea.

A quarter of a pound of fluorescein was introduced at P 73 at noon on June 29th, and was seen at S 103 at 3.30 p.m. on the same day. It again sank at P 74 and reappeared at S 104 at 3.35.

About 30 yards below S 104, the stream has been partially diverted to P 76, but a portion flows down the natural channel to P 75.

By turning the whole stream alternately down P 75 and P 76 it was possible to trace both lines of flow.

First the stream was turned down the normal channel to P 75, and the fluorescein was seen at P 77 at 4.35 p.m., where it again sank, and was seen half an hour later in P 78.

Secondly, the flow having been diverted into the artificial channel to P 76, the colour was seen in a trough at Brock Holes, the flow being partly by a natural channel parallel to the main joints in the limestone, and partly by a pipe to supply the trough.

Fluorescein was next put into P 67 and was traced by S 95, P 68, S 96, P 69, and S 97, to P 70, where it finally sank.

The fluorescein from all the above streams passed along the master joints and emerged at S 99, below the Station Hotel at Ribblehead, and subsequently at Batty Wife Hole, S 100. It then flowed overground to P 72, where it again sank, to come to light at S 101, near the bank of the Ribble below Gauber Farm, and so into the river.

The spring at S 101 is similar in appearance to Turn Dub previously described, but is much smaller.

In wet weather the excess of water from Batty Wife Hole flows over the surface, by way of Batty Wife Beck, into the Ribble, which it then joins some 300 yards further up-stream than the water which goes underground.

Sinks on Fell Close. [Pl. XXX.]

There are three streams flowing over Fell Close, viz., Keld Bank Spring East, sinking at P 79, Fairweather Spring East; sinking at P 80, and Fairweather Spring West at P 81.

These three streams were found to unite, and to issue at Eller Keld Spring, S 106, whence the water flows into the bed of Winterscale Beck, otherwise known as Haws Gill, where it again sinks to join the main drainage of Chapel-le-Dale, which will be described later.

Proceeding southwards, the next stream is Keld Bank Spring West, which sinks on Scar Close Moss, at P 82.

This stream rises on the N.W. slope of Simon Fell at a height of 1,750 feet at the base of the Yoredale Girt, sinks at 1,550 feet, passes through a thin limestone, and re-emerges at 1,450 feet at the base thereof.

About 100 yards to the south another stream rises at 1,700 feet, also passes through the thin limestone, re-emerges and flows parallel to Keld Bank Spring West, and finally joins that stream at 1,200 feet.

The combined streams sink at P 82 at a height of 1,150 feet. Fluorescein was put into P 82 at 12 noon on July 4th, and was seen at S 105 at 5 p.m. on the same day.

From S 105 the water flows overground for about thirty yards and again sinks at P 83.

The master joints at P 83 run N. 25° W., and the secondary joints N. 10° E.

Below P 83 is the enclosure known as Scar Close, the surface of which consists for the most part of bare limestone "clints."

Here the joints run S. 52° E., N. 28° E., and N. 48° E., the former being most strongly developed.

At the point marked P 84 on these clints running water can be seen at the bottom of one of the open joints at a depth of about 12 feet from the surface. This was seen to be coloured strongly by the fluorescein from P 83 on July 5th, the colour being also observed on that day in the waters of Eller Keld Spring S 106.

The presence of three sets of joints on Scar Close somewhat complicates matters, but it will be seen that the flow is on the whole parallel to the master joints from P 83 to P 84—while between P 82 and S 105 one of the secondary joints accounts for the direction of the underground stream, as is also the case between P 84 and Eller Keld Spring (S 106).

Passing southward along the Fell side from P 82 a group of small streams is found to sink at P 93 (1,200 feet) on Fenwick Lot. The water from this sink was traced to a small spring S 106a below Eller Keld Spring.

The next sink is that at the Washfold, P 96 (1,175 feet), on Souther Scales Fell, while a few yards to the south another stream sinks at P 94. These two streams unite below the Washfold.

The main joints at this point run N. 10° W., while the secondary series points N. 40° E.

The water takes the line of the former by way of Little Douk Cave to Douk Cave P 95.

Douk Cave is a deep ellipsoidal hollow with vertical walls round the greater part, the longer axis running approximately E. and W. [Pl. XXXVII.].

The bottom of this hollow consists of large fallen blocks and the hole probably owes its origin to the falling in of the roof of a large subterranean chamber.

At the eastern extremity of the hollow is a low cave from the mouth of which a waterfall discharges the stream from P 94 and P 96.

The cave has been traced for a considerable distance passing below Little Douk Cave, which is a vertical shaft opening into the roof of the passage.

Fluorescein was introduced at P 94 on June 30th at 2.30 p.m., and the colour was observed in the waterfall at Douk Cave at 3.50 the same afternoon.

Below the waterfall the stream passes down a series of cascades to the western end of the hole, where it sinks among the loose blocks of limestone mentioned above. The fluorescein was again observed in Chapel Beck, in the pool below God's Bridge, S 112, at 1 p.m. on July 3rd, and was much stronger at 2.30 p.m.

The stream was low at the time, and there was little water above God's Bridge. Weathercote Cave P 88 and Hurtle Pot P 90 were carefully watched from June 30th to July 3rd, but no trace of the colour was to be seen in either.

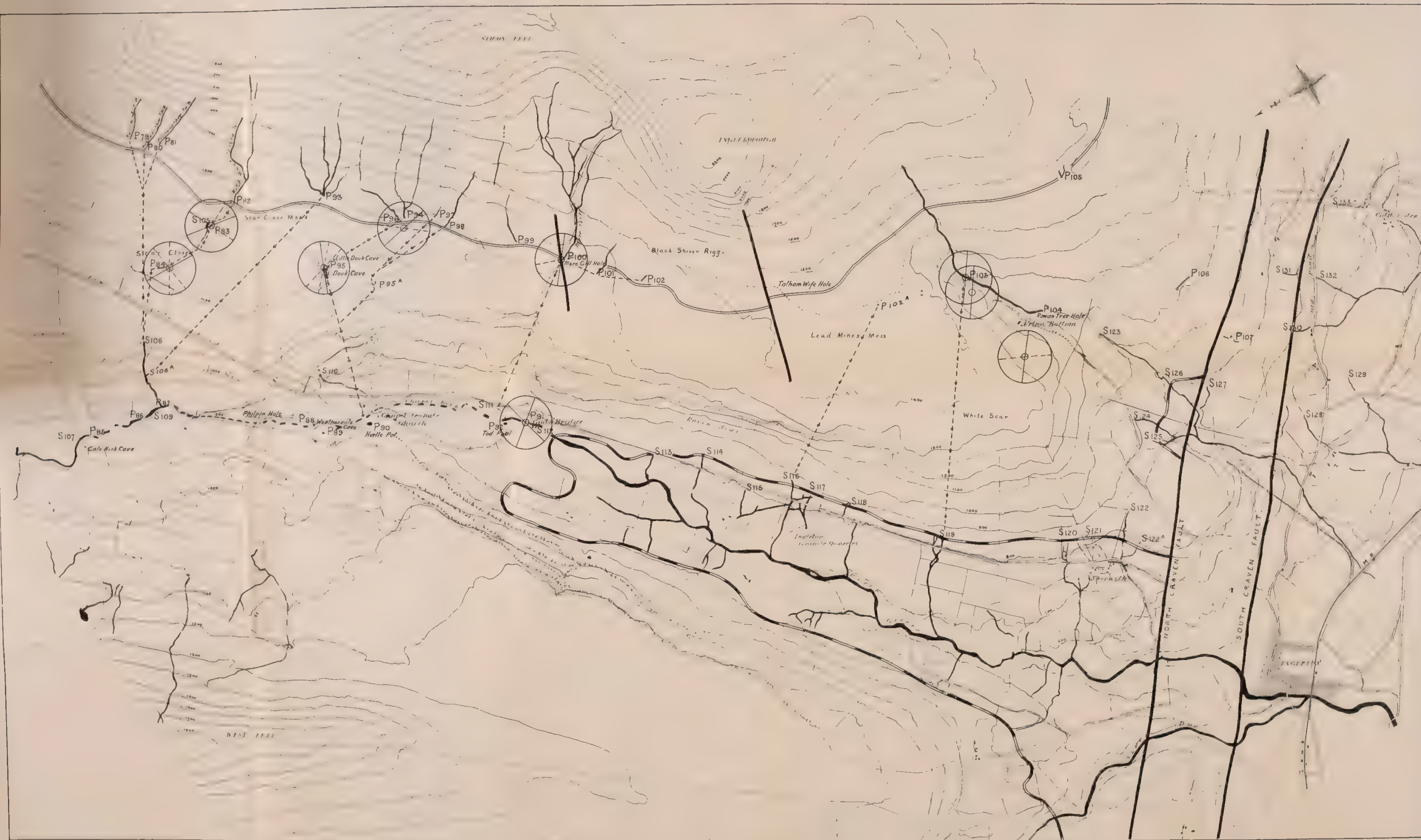
The conclusion arrived at was, therefore, that the water from Douk Cave joins Chapel Beck on some part of its underground journey between Hurtle Pot and God's Bridge.

The main joint at Douk Cave runs N. 65° W., and this, if continued, would strike Chapel Beck in the neighbourhood of the Vicarage, which agrees very well with the conclusion mentioned above. The secondary joints are N. 45° W. and N. 15° W.

UNDERGROUND WATERS OF N.W. YORKSHIRE.

CHAPEL-LE-DALE AREA.

SCALE.



Faults. Upper boundary of Carboniferous Limestone. Lower boundary of Carboniferous Limestone. Direction of Underground Flow.

P 97, a sink in the corner of the next enclosure to the south of the Washfold, on being tested was found to flow underground to Far Douk (P 95a), where the water again sank. The same was found to be the case with P 98 and P 99.

The fluorescein from Far Douk was seen two days later at God's Bridge S 112.

Reference to Pl. XXX. will show a remarkable parallelism in the flow of underground water on Sother Scales Fell. The streams between P 82 and P 99 (including these streams) following similar courses immediately they enter the limestone.

Mere Gill Hole.

At Mere Gill Hole there is a change in the direction of the main joints in the limestone, the strongest set running N. 50° W. —this being also a line of faulting, marked on the maps of the Geological Survey.

Mere Gill rises on the upper slopes of Ingleborough and flows down the hollow known as Humphry Bottom, and sinks in a large open joint running N. 50° W. at Mere Gill Hole, on Mere Gill Platt.

Mere Gill was charged with fluorescein at 1 p.m. on July 4th, and the colour was observed on the following morning in the spring S 111, on the left bank of Chapel Beck, immediately above God's Bridge, and almost in the direct line of the master joint at Mere Gill Hole. From S 111 the water passed under God's Bridge by way of P 91, and reappeared below the bridge at S 112.

P 101 and P 102 on Black Shiver Moss receive the waters of two small streams, the underground flow being to the lower end of Mere Gill Hole, where it joins the waters of Mere Gill, and again goes underground, the further course of the water being described above.

Tatham Wife Hole, at Falls Foot, was visited several times during the investigation, but was always dry and consequently could not be tested.

P 102a, on the eastern edge of Lead Mines Moss, not marked on the 6 inch Ordnance Map, receives a small stream in wet weather only. This, on being tested with fluorescein, was found to communicate with S 116, near the "Engine Sheds" at the Ingleton Granite Quarries.

From P 102a to the Crina Bottom Valley there are no sinks of importance, and the next stream to be studied was Hard Gill.

This stream rises, on the south side of Ingleborough, in a spring at 1,600 feet above the sea, and flows for a distance of about half a mile over boulder-clay. It then reaches the bare limestone and commences to sink near the eastern corner of the croft (P 103) at Crina Bottom [Pl. XLI., Fig. 1].

In wet weather the stream is not entirely absorbed at this point, but flows on past the house at Crina Bottom, and enters the rock at Rowan Tree Hole (Rantree Hole on 6 inch map), P 104.

At the time of the experiments the water of Hard Gill was entirely absorbed between the point where the 1,200-foot contour crosses the stream and the eastern corner of the croft, and consequently the investigation of Rowan Tree Hole, the primary object of the excursion, had to be abandoned.

It was found, however, that the bulk of the water was absorbed at the point where the 1,200-foot line crosses the stream, and consequently it was determined to introduce one pound of fluorescein into the open joint down which the water was flowing. This was done at 2 p.m. on November 11th, and before 7 a.m. on the 12th, the water of the large spring at the reservoir (S 119) in the Greeta Valley was strongly coloured, and by 8 a.m. the water in the Ingleton water pipes was also affected.

After introducing the fluorescein a general survey was made of the direction of the joints in the limestone in the neighbourhood of the sink and on the clints above Crina Bottom, with the following results :—

Joint at "sink"		N. 55° W.
On "clints" near sink		N. 55° W.
On "clints" above and to the west of Crina Bottom	(main)	N. 50° W.
	(secondary)	S. 25° W.

The spring at the reservoir is thrown out close to the line of junction of the Mountain Limestone with the underlying

Silurian rocks, and the line from the sink where the fluorescein was introduced to the spring runs N. 55° W.—that is, in the direction of the master joints in the limestone.

Thus, again, it was demonstrated that the direction of underground flow is determined by that of the master joints.

It is also of much interest to note that the spring S 119 lies in one of the valleys of the Silurian floor, as will be seen by comparing the direction of the line of outcrop with that of the contour lines [Pl. XXX.].

The springs S 110, S 113, S 114, S 115, S 117, S 118, S 120, S 121, S 122, S 122a, S 124, and S 125, having been unaffected by any of the tests employed it is concluded that they discharge the water collected by the open joints on the extensive clints on Lead Mines Moss and White Scar.

The River Greeta. [Pl. XXX.]

An interesting piece of work was the tracing of the underground course of the main stream in Chapel-le-Dale.

This stream flows underground in many places in normal weather, but when in flood occupies a well-worn channel on the surface.

The upper part of the stream, above Weathercote, is known as Winterscale Beck, the portion between Weathercote and God's Bridge as Chapel Beck, and from that point down to Ingleton as the River Greeta.

The stream rises on the moors near the tunnel of the Midland Railway, above the Ribblehead Viaduct, and soon sinks in a series of pot-holes, there being, however, a well-marked open flood channel.

The whole stream again comes to the surface at the mouth of Gate Kirk Cave, S 107, and another large spring a few yards away.

It then flows through several large pools, and again goes underground at P 85, leaving the stream bed dry, to again emerge about 70 yards further down at S 109. It again sinks at the foot of Haws Gill, P 87, where it is joined by the water from Eller Keld Spring (S 106 and S 106A).

Except in cases of exceptional flood the bed of the stream below this point is dry, and from the point where Philpin Lane crosses the channel, to Philpin Hole, it is occupied by meadow land, which shows no sign of having been recently overflowed.

In the clough above Weathercote Cave the water can be heard below the stream bed, and actually comes to the surface in several places in wet weather. It emerges in the fine waterfall in Weathercote Cave, and again passes below the limestone at the bottom of that pot [Pl. XXXVIII., Fig. 2].

The water, sinking in Weathercote Cave, then passes through the pool at the bottom of Hurtle Pot, and finds its way beneath the surface to God's Bridge [Pl. XXXIX., Fig. 2], where it finally comes to light, and flows off the Mountain Limestone on to the Silurian rocks some 200 yards farther down stream.

In extremely wet weather Weathercote Cave fills up and overflows at the surface, washing over the carriage drive, and flows into Jingle Pot (P 89), and also down the at other times deserted river bed.

Hurtle Pot, when the stream is in moderate flood, makes an extremely weird noise, similar to that produced by the inrush of water and air when the plug is removed from the bottom of a lavatory basin, but immeasurably louder. This noise is caused by the suction of air through gigantic eddies produced in the deep pool at the bottom of the pot.

In extremely heavy flood Hurtle Pot fills up and overflows into the surface channel, thus acting in a manner precisely similar to Footnaw's Hole, already described.

The surface channel from Chapel-le-Dale church to God's Bridge is usually dry, but is occupied by the stream when in flood.

The underground channel seems to follow the direction of the open one very closely, as the water can be heard at many points, and appears at the surface in wet weather.

The following is the fluorescein record from which the above has been deduced :—

Two pounds of fluorescein put into the stream just below the mouth of Gate Kirk Cave, on the morning of August 23rd.

Sank at P 85, and emerged at S 108 at 1 p.m.; sank at P 86 at 1.30 p.m.; seen at S 109 and P 87 at 2 p.m.

August 24th.—Seen in Weathercote Cave at 9.15 a.m.; seen in Hurtle Pot at 10.0 a.m.

August 25th.—Arrived at S 112 (God's Bridge) at 12 noon.

Between Hard Gill and Grey Wife Sike are a number of deep "pot-holes," the principal of which is Long Kin West (P 108). There is practically no water flowing down these pots and it was therefore impossible to test them [Pl. XXVI.].

The sink at Grey Wife Sike (P 1) above Newby Cote was first tested with Methylene Blue, but as this was not detected in any of the surrounding streams, fluorescein was tried, with the result that the water was traced to the large spring known as Moses' Well (S 7), just above the head of Clapham Lake.

This completes the circuit of the Ingleborough massif.

IV.—General Conclusions.

1. The flow of the underground waters of the area under consideration is radially outwards from the high ground, but is profoundly affected by the direction of the joints in the limestone, which in many cases considerably modify its course.

2. The irregularities in the floor of Silurian and Ordovician rocks on which the Carboniferous Limestone rests, form underground watersheds, which in some instances influence or even determine the direction of flow, as, for example, in the cases of Norber and Moughton, and the underground watershed between Gaping Ghyll and Long Kin East.

3. In many instances the subterranean streams are near the surface of the ground, and descend by a series of pitches, as in the case of Long Churn, while others plunge by way of vertical shafts to a depth often exceeding 200 feet from the surface. The joints in the limestone usually pass through one bed only, and are not vertically continuous through the whole mass, while, in some few instances, in which the deep vertical shafts occur, they cleave the limestone to its base. In one instance, Mere

Gill Hole, a fault marked on the maps of the Geological Survey, passes through the pot, while several others, e.g., Alum Pot, Rift Pot [Pl. XXXVIII., Fig. 1], and Long Kin West, strongly suggest a similar origin. It will be seen that a displacement, however small, and whether vertical or horizontal, involves the fracture of the limestone from top to bottom. Such continuous fractures are certainly present in the deep pots, though owing to the darkness and the accumulation of stalagmite it is extremely difficult to detect small displacements (faults).

4. Some, at least, of the caves and pot-holes are of pre-Glacial age, as, for example, Alum Pot and many of the deep pot-holes which are now partially filled with glacial débris, while others, such as Long Kin West, possibly owe their origin to glacier streams during the Glacial Period.

5. So strong is the influence of the joints in the limestone upon the direction of flow of the underground waters that there are several instances in which streams are carried beneath a surface watershed so as to emerge in a different drainage basin from that in which they took their rise.

6. As at Malham so in this district there occur streams which cross each other during their subterranean journeyings and others which pass beneath those on the surface of the ground.

ARTHUR R. DWERRYHOUSE.

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Photographed by Godfrey Bingley, Headingley, Leeds.

Fig. 1.

TROW GILL.

Photographed by Godfrey Bingley, Headingley, Leeds.

Fig. 2.

GAPING GHYLL.

Photographed by Godfrey Bingley, Headingley, Leeds.

Fig. 1.

GAPING GHYLL.

Photographed by Godfrey Bingley, Headingley, Leeds.

Fig. 2.

CLAPHAM BECK HEAD.

Photographed by Godfrey Bingley, Headingley, Leeds.

Fig. 1.

UPPER ENTRANCE TO LONG CHURN, P 31.

Photographed by Godfrey Bingley, Headingley, Leeds.

Fig. 2.

INTERIOR OF LONG CHURN.

Photographed by Godfrey Bingley, Headingley, Leeds.

Fig. 1.

MOUTH OF ALUM POT.

Photographed by S. W. Cuttriss, Leeds.

Fig. 2.

BRIDGE IN ALUM POT.

Photographed by Godfrey Bingley, Headingley, Leeds.

Fig. 1.

FOOTNAW'S HOLE.

Photographed by Godfrey Bingley, Headingley, Leeds.

Fig. 2.

TURN DUB.

Photographed by A. R. Dwerryhouse, Headingley, Leeds.

Fig. 1.

CLINTS NEAR DOUK CAVE.

Photographed by A. R. Dwerryhouse. Headingley, Leeds.

Fig. 2.

CLINTS NEAR SULBER NICK.

Photographed by A. R. Dwerryhouse, Headingley, Leeds.

Fig. 1.

DOUK CAVE.

Photographed by A. R. Dwerryhouse, Headingley, Leeds.

Fig. 2.

DOUK CAVE.

Photographed by A. R. Dwerryhouse, Headingley, Leeds

Fig. 1.

RIFT POT.

Photographed by S. W. Cuttriss, Leeds.

Fig. 2.

WEATHERCOTE CAVE.

Photographed by Godfrey Bingley, Headingley, Leeds.

Fig. 1.

AUSTWICK BECK HEAD.

Photographed by A. R. Dwerryhouse, Headingley, Leeds.

Fig. 2.

GOD'S BRIDGE, CHAPEL-LE-DALE.

Photographed by Godfrey Bingley, Headingley, Leeds.

Fig. 1.

SIDE OF MOUGHTON FROM CRUMMACKDALE.

Photographed by Godfrey Bingley, Headingley, Leeds.

Fig. 2.

UNCONFORMITY AT ARCO WOOD.

Photographed by A. R. Dwerryhouse, Headingley, Leeds.

Fig. 1.

CRINA BOTTOM.

Photographed by A. R. Dwerryhouse, Headingley, Leeds.

Fig. 2.

SPRING AT S 51.

and Diluvial Gravel, and on other Geological Phenomena, attesting the Action of an Universal Deluge (Kirkdale, &c., pp. 1, 173). 4to. London.

1832.

YOUNG, Rev. G.—On the Fossil Remains of Quadrupeds, &c., Discovered in the Cavern at Kirkdale, in Yorkshire, and in other Cavities or Seams in Limestone Rocks. Mem. Wernerian Soc., Vol. vi., p. 171.

1844.

SMITH, ROACH, and JOSEPH JACKSON.—On Victoria Cave. Collectanea Antiqua, Vol i., No. 5.

1849.

FARRER, J. W.—On Ingleborough Cave. Quart. Jnl. Geol. Soc., Vol. v., p. 49.

1853.

WEST, T.—On Certain Cavities in the Limestone District of Craven. Proc. Geol. and Polytech. Soc., W. Riding, Yorks., Vol. iii., p. 240.

1853.

PHILLIPS, J.—The Rivers, Mountains, and Sea-coast of Yorkshire. London, J. Murray, Albemarle Street.

1860.

DENNY, H.—On the Geological and Archæological Contents of the Victoria and Dowkabottom Caves in Craven. Proc. Geol. and Polyt. Soc., W. Riding, Yorks., Vol. iv., p. 45.

1861.

SALMON, H. C.—(Letters on) New Caverns in Yorkshire. Geologist, Vol. iv., p. 312.

1862.

BARROW, T. W.—Remarks on the Bone Caves of Craven. Rep. Brit. Assn. for 1861, p. 108.

1865.

DAWKINS, W. B.—On the Mammalian Remains found by E. Wood, near Richmond, Yorkshire. With an Introductory Note on the Deposit in which they were found; by E. Wood and G. E. Roberts. Quart. Jnl. Geol. Soc., Vol. xxi., p. 493.

1865.

SMITH, ECKROYD.—The Limestone Caves of Craven. Trans. Hist. Soc., Cheshire.

1865.

FARRER, J. W.—Further Explorations in the Dowkabottom Caves in Craven. With Remarks by Hy. Denny. Proc. Geol. and Polyt. Soc., W. Riding, Yorks., Vol. iv., p. 414.

1870.

DAWKINS, W. B.—Exploration of Caves at Settle, Yorkshire. Nature, Vol. i., p. 628.

1870.

MIALL, L. C.—On the Formation of Swallow Holes or Pits with Vertical Sides in Mountain Limestone (Swaledale). (Brit. Assoc.) Geol. Mag., Vol. vii., p. 513, and Nature, Vol. ii., p. 526.

1871.

DAWKINS, W. B.—Exploration of the Victoria Cave, Settle, Yorkshire. Rep. Brit. Assn. for 1870, p. 148 ; Nature, Vol. v., p. 135.

1871.

DAWKINS, W. B.—(Short Account of the Discoveries in the Victoria Cave made since the last Account was published). Proc. Lit. and Phil. Soc., Manchester, Vol. xi., No. 2, p. 9.

1871.

DAWKINS, W. B.—On the Formation of the Caves around Ingleborough. Trans. Mchr. Geol. Soc., Vol. x., No. 2, p. 106.

1871.

MORRISON, W.—On the Exploration of the Settle Caves, Yorkshire. Trans. Plymouth Inst., Vol. iv., Part 2, p. 108.

1872.

DAWKINS, W. B.—Report of the Results obtained by the Settle Cave Exploration Committee out of Victoria Cave in 1870. Jnl. Anthrop. Inst., Vol. i., p. 60.

1872.

DAWKINS, W. B.—Discovery of Extinct Mammals in the Victoria Caves, Settle. Nature, Vol. vi., No. 137, p. 127.

1873.

Brockbank, W.—Notes on the Victoria Cave, Settle. Manchester Lit. and Phil. Soc., No. 180, pp. 455–6.

1873.

Busk, Prof. G.—Man in the Settle Cave. Nature, Vol. ix., p. 70.

1873.

Dawkins, W. B., and R. H. Tiddeman.—Report on the Victoria Cave explored by the Settle Cave Exploration Committee (abstract). Rep. Brit. Assn. for 1873, p. 178.

1873.

Dawkins, W. B.—Report on the Results obtained by the Settle Cave Exploration Committee of Victoria Cave in 1870. Jnl. Anthrop. Inst., Vol. i., No. 1, p. 60, also Nature, Vol. vii., No. 176, pp. 374–375, Manchester Lit. and Phil. Soc.

1873.

Dawkins, W. B.—Observations on the Rate at which Stalagmite is being accumulated in the Ingleborough Cave (Mchr. Lit. and Phil. Soc.). Nature, Vol. vii., No. 180, p. 455.

1873.

Fisher, Rev. O.—(Letters on) The Settle Cave Deposits. Geol. Mag., Vol. x., p. 95.

1873.

Tiddeman, R. H.—The Older Deposits in the Victoria Cave, Settle, Yorkshire. Geol. Mag., Vol. x., p. 11.

1873.

Tiddeman, R. H.—Report on the Victoria Cave. The Physical History of the Deposit. Rep. Brit. Assc. for 1872, p. 179.

1873.

Tiddeman, R. H.—The Slow Deposits in the Victoria Cave, Settle. Geol. Mag., Vol. x., p. xi.

1873.

Tiddeman, R. H.—The Relation of Man to the Ice Sheet in the North of England. Nature, Vol. ix., No. 210, p. 14.

1874.

Busk, Prof. G.—Notice of a Human Fibula of Unusual Form discovered in the Victoria Cave, near Settle, Yorkshire. Jrnl. Anthrop. Inst., Vol. iii., pp. 392–395.

1874.

Dawkins, W. B.—Report of the Committee appointed for the purpose of Exploring Settle Caves. Rep. Brit. Assc., 1873, pp. 250–251.

1874.

Dawkins, W. B.—Observations on the Rate at which Stalgamite is being accumulated in the Ingleborough Cave. Rep. Brit. Assc. for 1873, p. 80 (see also Proc. Mchr. Lit. and Phil. Soc., Feb., 1873).

1874.

Dawkins, W. B.—Cave Hunting. Researches on the Evidence of Caves respecting the Early Inhabitants of Europe (coloured plate and woodcuts), pp. xix., 455, Chap. iii., 8vo. London.

1874.

Ellis, J. W.—Note on the Stump Cross Caverns at Greenhow, near Pateley Bridge. Rep. Brit. Assc. for 1873. Sec., p. 80.

1874.

Hughes, Prof. T. McK.—Exploration of Cave Ha, near Giggleswick. Jrnl. Anthrop. Inst., Vol. iii., No. 3, pp. 383–387.

1874.

Plant, J.—On Bones of Elephas Primigenius from a Cavern near Skipton. Trans. Geol. Soc. Mchr., Vol. xiii., Part 3, p. 54.

1875.

Tiddeman, R. H.—Second Report of the Committee appointed for the purpose of Assisting in the Exploration of the Settle Caves (Victoria Cave). Rep. Brit. Assn. for 1874, pp. 133–138. Reprinted, 8vo. Lancaster.

1876.

Jones, Prof. T. R.—The Antiquity of Man, illustrated by the Contents of the Caves and the Relics of the Cave Folks. Geol. Mag., Dec. 2, Vol iii., pp. 269–272 (abstract of Lecture to the Croydon Microscopical Club).

1876.

MARR, J. E.—Note on the Occurrence of Phosphorised Carbonate of Lime at Cave Ha (near Settle), Yorkshire. Geol. Mag., Dec. 2, Vol. iii., p. 268.

1876.

TIDDEMAN, R. H.—Third Report of the Committee appointed for the purpose of assisting in the Exploration of the Settle Caves (Victoria Cave). Rep. Brit. Assc. for 1875, pp. 166–175. Two photographs.

1876.

TIDDEMAN, R. H.—The Work and Problems of the Victoria Cave Explorations. Proc. of Geol. and Polyt. Soc. of W. Riding of Yorks., New Series, Part 2, pp. 77–92.

1877.

TIDDEMAN, R. H.—Fourth Report of the Committee appointed for the purpose of assisting in the Exploration of the Settle Caves (Victoria Cave). Rep. Brit. Assc. for 1876, pp. 115–118.

1877.

DAWKINS, W. B.—Caves. Encycl. Brit., Ed. 9, Vol v.

1877.

DAKYNS, J. R.—The Antiquity of Man. Geol. Mag., Dec. 2, Vol. iv., pp. 439–441.

1877.

TIDDEMAN, R. H.—Fifth Report of the Committee appointed for the purpose of assisting in the Exploration of the Settle Caves (Victoria Cave). Rep. Brit. Assc., 1877, p. 215.

1878.

TIDDEMAN, R. H.—Sixth Report on the Exploration of the Settle Caves (Victoria Cave). Rep. Brit. Assc. for 1878, pp. 377–380.

1878.

DAVIS, J. W., and LEES, F. A.—West Yorkshire, an Account of its Geology, Physical Geography, Climatology, and Botany. With maps and plates. London, L. Reeve & Co.

1879.

CAMERON, A. G.—Ripon Swallow Holes. Proceedings Yorks. Geol. and Polyt. Soc., Vol. vii., p. 342.

1879.

MIALL, Prof. L. C.—Cave at Raygill. Proc. Yorks. Geol. and Polyt. Soc., Vol. vii., p. 207.

1880.

Report of the Raygill Fissure Exploration Committee. Yorks. Geol. and Polyt. Soc., New Series, Vol. vii., pp. 300–306.

1880.

TATE, T.—The Source of the River Aire. Proc. Yorks. Geol. and Polyt. Soc., Vol. vii., Part ii., pp. 177–186.

1880.

MIALL, L. C.—The Cave (Raygill Fissure) and its Contents. Proc. Yorks. Geol. and Polyt. Soc., New Series, Vol. vii., Part ii., pp. 207–208.

1880.

DAWKINS, W. B.—On the Action of Carbonic Acid on Limestone. Rep. Brit. Assc. for 1880, p. 573, and Geol. Mag., Dec. 2, Vol vii., p. 514—Caves in Caldy Island and in Yorkshire.

1881.

DAVIS, J. W.—Report of the Raygill Fissure Exploration Committee. Proc. Yorks. Geol. and Polyt. Soc., New Series, Vol. vii., Part iii., pp. 300–306.

1882.

POULTON E. B.—A Preliminary Account of the Working of Dowkabottom Cave, in Craven, during August and September, 1881. Proc. Yorks. Geol. and Polyt. Soc., New Series, Vol. vii., Part iv., pp. 351–368. Rep. Brit Assn. for 1881, pp. 622–623.

1882.

DAVIS, J. W.—On the Exploration of a Fissure in the Mountain Limestone at Raygill. Rep. Brit. Assc. for 1881, pp. 645–646.

1883.

DAVIS, J. W.—Report of the Committee appointed to assist in the Exploration of Raygill Fissure, Yorkshire. Rep. Brit. Assc. for 1883, pp. 133–135.

1884.

DAVIS, J. W.—Report of the Committee to assist in Exploration of Raygill Fissure, Yorkshire. Rep. Brit. Assc. for 1884, p. 240.

1884.

CLARKE, T. J.—The Yorkshire Caves, a Three Days' Trip with the Tyneside Field Club. Nat. Hist. Trans. Northumberland, Durham and Newcastle, Vol. viii., pp. 50–67.

1886.

Cave Hunting in Yorkshire. Chamber's Journal, No. 146, Vol. iii., pp. 657–660.

1886.

DAVIS, J. W.—Report of the Committee, &c., for Raygill Fissure, Yorkshire. Rep. Brit. Assc., pp. 469–470.

1886.

DAVIS, J. W.—On the Exploration of the Raygill Fissure in Lothersdale. New Series, Vol. ix., pp. 280–281, Proc. Yorks. Geol. and Polyt. Soc.

1887.

HUGHES, T. McK.—On Caves. Paper read before the Victoria Institute, London. Published by the Institute.

1887.

TIDDEMAN, R. H.—On the Age of the Hyæna Bed at the Victoria Cave, Settle, and its Bearings on the Antiquity of Man. Quart. Jnl. Anthrop Inst., 1887.

1888.

JONES, Rev. E.—On the Exploration of a Cave at Elbolton, near Thorpe. Proc. Yorks. Geol. and Polyt. Soc., New Series, Vol. xi., pp. 86–90.

1888.

ANONYMOUS.—Goyden Pot. Chamber's Journal for June, 1888.

1889.

JONES, Rev. E.—On the Further Exploration of a Cave at Elbolton, near Thorpe in Craven. Proc. Yorks. Geol. and Polyt. Soc. New Series, Vol. xi., pp. 307–310.

1889.

Cave Explorations. Proc. Yorks. Geol. and Polyt. Soc., New Series, Vol. x., pp. 283–310.

1889.

TIDDEMAN, R. H.—On Concurrent Faulting and Deposit in Carboniferous Times in Craven, Yorkshire. Rep. Brit. Assc. for 1889, pp. 600–603.

1890.

JONES, Rev. E.—Elbolton Cave Exploration. Rep. Brit. Assc. for 1890, pp. 817–818.

1890.

THOMPSON, Prof. S. P.—Sources of the River Aire. Rep. Brit. Assc. for 1890, pp. 821–822.

1890.

DAKYNS, TIDDEMAN, GUNN and STRAHAN.—Memoir of the Geological Survey. The Geology of the Country around Ingleborough, with parts of Wensleydale and Wharfedale. (Explanation of Quarter Sheet 97 S.W., New Series, Sheet 50.) London, Eyre & Spottiswood.

1891.

JONES, Rev. E.—Exploration of the Elbolton Cave. Proc. Yorks. Geol. and Polyt. Soc., New Series, Vol. xii., pp. 105–7.

1891.

Report of the Committee on the Investigation of the Cave at Elbolton, near Skipton. Rep. Brit. Assc. for 1891, pp. 351–353.

1892.

Report of the Committee on Investigation of the Cave at Elbolton, near Skipton. Rep. Brit. Assc. for 1892, p. 266.

1892.

BOGG, E.—A Thousand Miles in Wharfedale. London, Simkin, Marshall, Hamilton, Kent & Co. Ltd., and E. Bogg, Leeds, pp. 242–244.

1892.

SPEIGHT, H.—The Craven and North-west Yorkshire Highlands. Illustrated. London, Elliot Stock, 62, Paternoster Row.

1894.

SPEIGHT, H.—Nidderdale and the Garden of the Nidd. Illustrated. London, Elliot Stock, 62, Paternoster Row.

1894.

Report of the Committee on the Investigation of the Cave at Elbolton. Rep. Brit. Assc. for 1894, pp. 270–271.

1894.

Exploration of the Calf Hole Cave, near Skyrethorns, near Skipton. Rep. Brit. Assc. for 1894, pp. 272–273.

1895.

MARTEL, E. A.—Sous Terre-Annuaire du Club Alpin Français. 22c Vol., 1895.

1897.

MARTEL, E. A.—Irlande et Cavernes Anglaises. Paris, Librairie Ch. Delagrave, 15, Rue Soufflot.

1897.

WOOD, W.—In Subterranean Caves. Gentleman's Mag., Mar., 1897, p. 303.

1898.

BOGG, E.—The Border Country, Lakeland and Ribblesdale. E. Bogg, Leeds, pp. 231–243.

[No date.]

BALDERSTON, R. R.—Ingleton, Bygone and Present. London, Marshall & Co., and Skipton, Edmondson & Co.

1898.

HICKS, Dr. H.—Evidences of the Antiquity of Man furnished by Ossiferous Caverns in Glaciated Districts in Britain. Geol. Soc., Feb. 18 (Nature, Feb., 1898, p. 402).

1898.

Bone Caves at Settle. Quart. Jnl. Geol. Soc., Vol. xxxii., Proc., p. 113.

1898.

J. A. Green, E. Calvert, F. Ellet, T. Gray.—Cave Exploration. The Encyclopædia of Sport, Part xi., pp. 48–53. Lawrence and Bullen, London.

1898.

Cuttriss, S. W.—Notes on the Caves of Yorkshire. Proceedings of the Yorks. Geol. and Polyt. Soc., Vol. xiii., Part iii., pp. 311 to 324.

1899.

Handby, J. Walling.—Cave Finds in Ribblesdale. The Naturalist, January, 1899, p. 32.

1898.

Cuttriss, S. W.—Notes on the Caves of Yorkshire. Proceedings of the Yorks. Geol. and Polyt. Soc., Vol. xiii., Part iv., pp. 433 to 443.

1898.

La Descente de Rowten Pot (Yorkshire, Angleterre). With plans and illustrations. Spelunca 4, 31–39.

1899.

Cuttriss, S. W.—The Caves and Pot Holes of Yorkshire. The Yorkshire Ramblers' Club Journal, No. 1, Vol. i., July, 1899, pp. 54–64.

1899.

Calvert, Ed.—Gaping Ghyll Hole. The Yorkshire Ramblers' Club Journal, No. 1, Vol. i., July, 1899, pp. 65–74.

1899.

Cuttriss, S. W.—Notes on the Caves of Yorkshire. Part ii. Proc. Yorks. Geol. and Polyt. Soc., Vol. xiii., Part iv., pp. 433-443.

1900.

Ellet, Frank.—Long Kin Hole, West. The Yorkshire Ramblers' Club Journal, No. 2, Vol. i., January, 1900, pp. 114–122.

1900.

Calvert, Ed.—Gaping Ghyll Hole, II. The Yorkshire Ramblers' Club Journal, No. 2, Vol. i., January, 1900, pp. 123–133.

1900.

The Underground Waters of North-West Yorkshire. Part i. The Sources of the Aire.

I. Introduction. By J. H. Howarth, F.G.S.

II. Engineering Report. By C. W. Fennell, F.G.S., and J. A. Bean, C.E.

III. Report of the Chemical Sub-Committee. By F. W. Branson, F.I.C., and W. Ackroyd, F.I.C.

IV. Report of the Geological Sub-Committee. By P. F. Kendall, F.G.S., J. H. Howarth, F.G.S., and W. Lower Carter, M.A., F.G.S.

Appendix. Malham Tarn Flushes and Malham Cove. By. Percy F. Kendall, F.G.S.

Proc. Yorks. Geol. and Polyt. Soc., Vol. xiv., Part i., pp. 1-44.

1900.

Burrell, B. A., F.I.C.—The Composition of Some Malham Waters. Proc. Yorks. Geol. and Polyt. Soc., Vol. xiv., Part. i., pp. 45-48.

1901.

Green, J. A.—Two Explorations in Ingleborough Cave, pp. 220–228. Alum Pot, pp. 233–234. The Yorkshire Ramblers' Club Journal, No. 3, Vol. 1, 1901.

1902.

Swithenbank, J. W.—Rowten Pot. The Yorkshire Ramblers' Club Journal, No. 4, Vol. i., 1902, pp. 316–324.

1903.

Lowe, G. T.—Alum Pot. The Yorkshire Ramblers' Club Journal, No. 5, Vol. i., 1903, pp. 35–47.

1903.

Cuttriss, S. W.—Gaping Ghyll Hole. The Yorkshire Ramblers' Club Journal, No. 5, Vol. i., 1903, pp. 48–51.

1903.

Green, J. A.—Early Explorations in Ingleborough Cave. The Yorkshire Ramblers' Club Journal, No. 5, Vol. i., 1903, pp. 52–63.

FIELD EXCURSION TO CROMER, NORWICH, AND LOWESTOFT.

JULY 9TH–14TH, 1903.

BY F. W. HARMER, F.G.S.

The special object of this excursion was to study, as far as might be possible during the short time allotted to it, the Glacial deposits of Norfolk, and their relation to those of the North of England.*

Assembling the night before at Tucker's Royal Hotel, Cromer, the excursionists took train to North Walsham on the morning of Thursday, July 9th, proceeding thence by carriage to Hasboro' (Happisburgh), at the south-eastern termination of the cliff section. A pleasant walk of about eight miles along the beach, in delightful weather, which fortunately lasted during the whole visit, brought them to Trimingham; there a conveyance awaited them for North Walsham, from whence they returned to Cromer in the evening.

The Pleistocene beds of East Anglia were divided by the late Searles V. Wood, Jun., into Lower, Middle, and Upper, those of the North Norfolk coast, the Cromer Till and the Contorted Drift, being placed by him in the first division. The Cromer Till, a bed of tough unstratified boulder-clay, of a dark blue colour, occurs at Hasboro' at the base of the cliff, there about 30 feet in height. It was seen to contain abundantly fragments of grey flint and hard chalk from the Wolds of Lincolnshire or Yorkshire, some of the chalk being scratched or striated, together with many broken shells of recent species, especially *Tellina balthica*, *Cardium edule*, and *Cyprina islandica*. Mr. Clement Reid has noted the much less frequent occurrence in the till of Red Chalk, Kimeridge Clay, and of detritus from the Lias, the Trias, and the Carboniferous strata, together with boulders of igneous rocks, some of which are of Scandinavian origin. Prof. P. F. Kendall, who joined the party at Hasboro', announced the discovery a few days before, at Bacton, three

* Reference is suggested to the admirable contour maps of Norfolk and Suffolk, recently published by Bartholomew (1s. each), on the scale of two miles to the inch.

miles to the N.W., of a large block of laurvikite from the Christiania Fiord, and a second boulder of the same kind was noticed during the day.

Overlying the till at this spot are some finely laminated and ripple-marked beds, the sediment possibly of a stream issuing from beneath the ice during its partial or local retreat. Above these is an upper boulder-clay, containing much soft chalk and black flint, regarded by Mr. Reid as a second till, but by Wood as forming part of the Contorted Drift. Speaking generally, it may be stated that the Jurassic detritus which forms such a marked feature of the Chalky Boulder-clay (Upper Glacial of Wood) is conspicuous by its absence from the drifts of the Cromer section. Pl. XLII., copied from one of the charming photographs taken by Mr. Godfrey Bingley during the excursion,* gives a characteristic representation of the disturbances which the Lower Glacial beds of this district have undergone; these are not confined, however, to that portion of the latter which generally goes under the name of the "Contorted Drift," but have also affected in some places the sands and gravels associated with it, and in others the basement till itself, as shown in the photograph.

The post-glacial river bed at Mundesley, six miles N.W. of Hasboro', described by Lyell† and others, was found to be no longer visible owing to the improvements (?) now being carried on at that rising watering place.

At Trimingham the Chalk appears on the fore-shore, having been forced up above its normal level by the North Sea ice, so as to form a projecting bluff. This bed is believed to belong to a higher zone than any other part of the Cretaceous deposits of England—that of *Ostrea lunata*—and to represent the Chalk of Maestricht and Rügen.

Taking a conveyance to Weybourne, at the other end of the cliff section, on the morning of Friday, July 10th, a walk

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* It would be difficult to over-estimate the value of Mr. Bingley's services on this occasion, involving him, it is to be feared, in considerable trouble and fatigue. The illustrations given in this paper are copied from his photographs.

† "Antiquity of Man," 1st Ed., p. 223, 1863.

Photographed by Godfrey Bingley, Headingley, Leeds.

CLIFF SECTION NEAR HASBORO', SHOWING THE BASEMENT TILL, CONTORTED, AND THE OVERLYING CONTORTED DRIFT.

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

of about seven miles along the beach to Cromer gave an opportunity for the examination of the Lower Glacial, and some of the later Pliocene deposits lying to the west of the latter place.

At Weybourne, and towards Sheringham, the Weybourne bed, the latest horizon of the Crag formation, was observed resting on the Chalk, the Contorted Drift occupying the upper part of the cliff. A bed of unworn flints may be seen here, as elsewhere, at the base of the Crag. It is from similar beds of a *remanié* character, occurring also at the base of different horizons of the Crag, that the remains of Mastodon and other mammalia, often in a highly phosphatized condition, have been found. Such fossils have been regarded as of the age of the deposits under (not in) which they are found. The writer believes, however, they are derivative, equally with the flints and phosphatic nodules with which they are associated. The bottom of the German Ocean is not littered with the bones and teeth of contemporary animals at the present day, and it is improbable that such was the case in Pliocene times ; moreover, these fossils seem of a much older type than the molluscan fauna of the Crag.

The fauna of the Weybourne deposit is exceedingly poor compared with the older zones of the Crag formation, comprising only 50 or 60 species of mollusca, as against more than 400 known from the Coralline Crag. The southern shells which characterised the latter had disappeared from the North Sea basin at this period, and had been replaced by others of a strongly boreal character. It is somewhat puzzling therefore to find that a few rare specimens of the southern or extinct species of the earlier Crag re-appeared afterwards in the Middle Glacial Sands.

The so-called "Forest-Bed" strata, which occur at the base of the cliff, are not well exposed, being often covered by the beach or by the accumulation of talus. They do not represent the site of an ancient woodland, as formerly supposed, but the estuarine deposits of the Rhine and its affluents, or the freshwater beds which accumulated near the margin of that river. The fossil remains of the larger mammalia, principally the bones or teeth of the southern form, *Elephas meridionalis*, are only met with in the former. They are always in a fragmentary condition, and were probably derived from carcases floated down, possibly from some distance, in times of flood. This part of the fauna has, generally, a southern character.

An exposure of the freshwater beds was observed at West Runton, in the form of peaty sand with freshwater shells. *Cyrena flumenalis*, with some other terrestrial and fluviatile mollusca not now living in England, occurs at this place, and it was here that Mr. Reid obtained a collection of small mammals, birds, reptiles, and fishes, and a flora similar to that of the Norfolk Broads at the present day. While, therefore, the fauna and flora of the freshwater part of the Forest-Bed series lived near the spot where they are found, the elephant remains of the estuarine portion may belong to some region to the south of Great Britain.

Further east, towards Cromer, the estuarine gravels with *Astarte* and *Tellina balthica* were observed, resting on the Chalk.

Pl. XLIII. shows one of the great masses, now of chalk, and again of marl, which are characteristic of the Cromer drifts. The one here represented was 200 yards long and 60 feet high forty years ago, but it is being gradually destroyed by the encroachment of the sea upon the coast. Such marl masses are of more frequent occurrence towards the western portion of the cliff section; indeed, in part of North-west Norfolk, as near Wells, the country is covered by a thick sheet of material undistinguishable from that of the great boulder shown in the photograph.

The most probable hypothesis of the origin of the Glacial deposits of the Cromer coast seems to be that they were due to the action of ice moving southward along the coasts of Yorkshire and Lincolnshire, which picked up in its course, here and there, a stray erratic from the western edge of the Scandinavian Glacier, or from the bed of the North Sea.

During the evening of the same day the General Meeting of the Society was held at Cromer, Mr. Godfrey Bingley in the chair, the subject previously announced for consideration being "The Glacial Deposits of East Anglia, and their relation to

Photographed by Godfrey Bingley, Headingley, Leeds.

ENORMOUS BOULDER OF CHALKY MARL IN THE CONTORTED DRIFT NEAR WEST RUNTON.

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

beds of the same age in the North of England." As introductory to this, the following paper (see page 315) was read, and followed by a discussion, in which Prof. Kendall, the Rev. W. Lower Carter, and others took part.

Following the programme agreed on, the party left Cromer on the morning of Saturday, July 11th, for Norwich, making their headquarters there at the Royal Hotel.

An important series of sections were first visited near to a road gradually rising northwards from the city towards Sprowston, Catton, and Hellesdon.

The lowest of these (Pl. XLIV.) showed the Crag sands, here unfossiliferous, resting on the unglaciated surface of the Chalk, and overlain by pebbly gravel. In another pit (Pl. XLV.), at a somewhat higher level than the last, the sandy brickearths of the Lower Glacial series, into which the Contorted Drift of the coast passes horizontally inland, were observed to be overlain in section by the Middle Glacial sands. These brickearths give slight but unmistakeable evidence of ice action, indicating probably that it was becoming feeble and dying out in this direction.* At Hellesdon brickyard, belonging to Mr. Alderman Cunnell, of Norwich,† some small boulders of Shap granite and rhomb-porphyry, identified by Prof. Kendall, were noted.

At a somewhat higher level, a section of the "Cannon Shot" gravels, which are largely developed on Mousehold Heath, to the north of the city (Pl. XLVI.), was visited. Although the Chalky Boulder-clay is absent from this section there is little doubt that these gravels are newer than that deposit. In many other places, indeed, they rest upon it. They are possibly

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* It should be specially noticed that the slight contortions observed in the Lower Glacial brickearths of this spot, which are hardly to be seen in the photograph (Pl. XLV.), were anterior to the deposition of the overlying Middle Glacial sands. The latter are quite undisturbed and rest on the former with an even line.

† Our thanks are due to Alderman Cunnell for permission to examine his extensive quarries, and for his kind hospitality on the occasion of our visit.

of a morainic character, accumulated during the retreat or melting of the Upper Glacial ice. Coarse gravels of similar character occupy the high land to the south of Cromer and Sheringham. I formerly regarded these as equivalent to the Middle Glacial sands of Suffolk, and they are so shown in the map published by Wood and myself in 1872.* I now think this was an error, and that they bear the same relation to the Contorted Drift, that the gravels of Mousehold Heath do to the Chalky Boulder-clay.†

A visit was afterwards paid to the Norwich Crag pit, at Thorpe, known to Samuel Woodward and the East Anglian geologists at the beginning of last century. The fossiliferous Crag sands are here overlain by pebbly gravels, as in the sections previously alluded to, and rest on the undisturbed surface of the Chalk.

The Lower Glacial clays and the Middle Glacial sands occur on higher ground immediately above this pit, in their usual sequence, as shown in the section, Fig. 1.

At another pit, however, below the first-named, the Chalky Boulder-clay has ploughed its way down to the Chalk, disturbing it and the overlying Crag beds, while still lower, nearer the bottom of the valley, it rests on the marly and glaciated surface of the former.

Up to this time the attention of the party had been principally directed to the Lower Glacial deposits, as to the connection of which with the North Sea ice there seems to be little doubt. The two following days were to be given to the district to the south of Norwich, the Upper Glacial deposits of which are, on the contrary, in the writer's opinion, the product of an inland ice stream.

On the morning of Monday, July 13th, the geological party took train for Lowestoft, and at a large excavation at Pakefield, a mile or two south of that town, made a further acquaintance with the Chalky Boulder-clay, the most important as it has been perhaps the least studied of the Glacial beds of East Anglia.

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* Palæontographical Soc. Supplement to the Crag Mollusca, 1872.

† I hope to give my reasons for this view in a future paper.

Photographed by Godfrey Bingley, Headingley, Leeds.

QUARRY AT SPROWSTON, NEAR NORWICH, SHOWING PEBBLY GRAVEL, AND CRAG SANDS (UNFOSSILIFEROUS), RESTING ON UNDISTURBED CHALK.

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

At Pakefield this deposit, which there rests on the Middle Glacial sand, is of a dark indigo colour, and of a tough, sticky character, and is composed to a large extent of Kimeridge Clay material. The hard chalk and grey flint of the Wolds are very common in it, and in this district Neocomian detritus is not rare; a few boulders of dolerite or diabase were noticed here, and one of porphyrite.

A great part of the area included in Sheets 50 and 66 (see Fig. 4) is covered by boulder-clay resembling in every respect that of Pakefield; see, for example, Pl. XLVII., copied from a photograph of a railway cutting near Forncett Station, more than 20 miles to the west of the former place, which was visited on the following day. This immense sheet of homogeneous material, always more or less Kimeridgian, and sometimes nearly 100 feet in thickness, which covers more than 1,000 square miles of country, seems to the writer to have been due, as stated in the paper read at Cromer, to an ice stream from the Fens, which to some extent excavated, or at least deepened the gap in the Chalk escarpment between Swaffham and Newmarket, pouring in great volume through it, and along the low

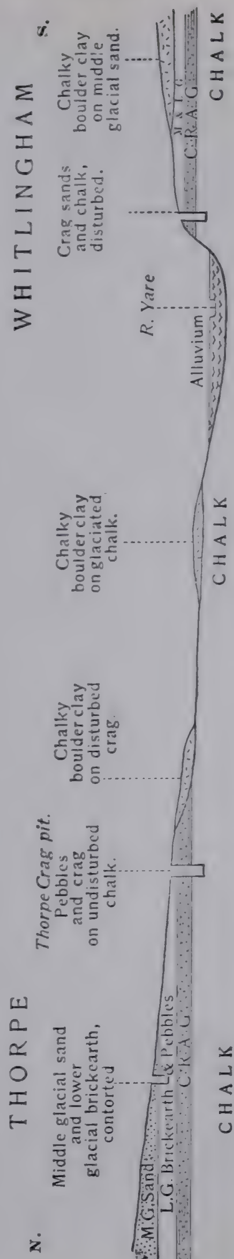

Fig. 1.

SECTION ACROSS THE VALLEY OF THE WENSUM, AT THORPE, NEAR NORWICH.

ground of the Little Ouse and Waveney depression, over the lower part of which the subjacent level of the Chalk hardly exceeds from 50 to 100 feet above the sea level. The Chalky Boulder-clay ice of this region came straight from the nearest Kimeridge Clay outcrop; the Fen basin was the quarry from which this part of its great moraine was excavated.

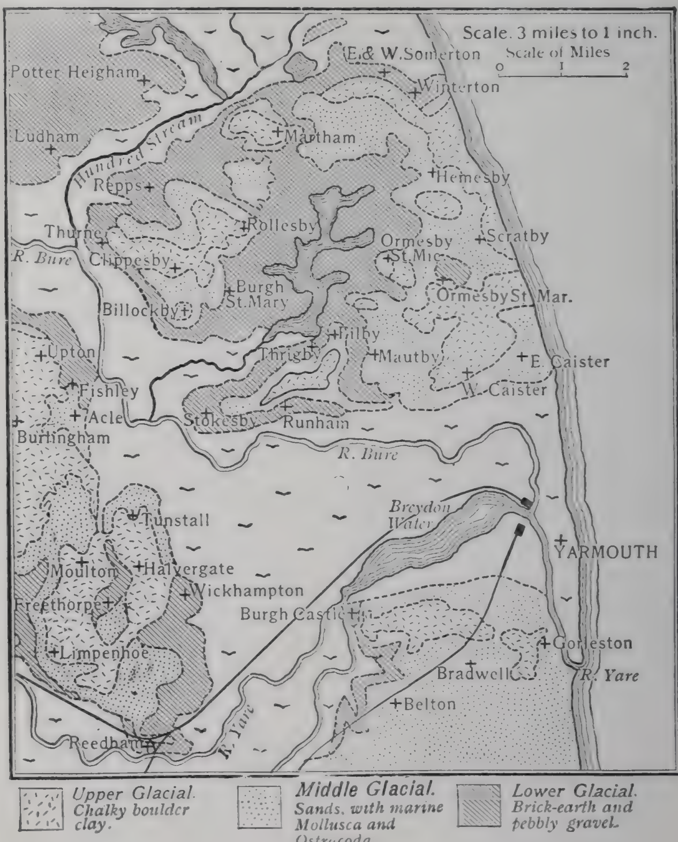

Fig. 2.

THE FLEGG HUNDRED.

For some miles to the N. of Kessingland, at the southern end of the Lowestoft cliff section, the Upper Glacial clay rests on the undisturbed surface of the Middle Glacial sands. For

Photographed by Godfrey Bingley, Headingley, Leeds.

SECTION NEAR THE LAST, BUT ON HIGHER GROUND, SHOWING CANNON-SHOT GRAVEL AND MIDDLE GLACIAL SAND ON CONTORTED DRIFT. PLATES XLV. AND XLVI. REPRESENT THE COMPLETE SERIES OF THE GLACIAL DEPOSITS OF THIS LOCALITY.

this fact, which is both interesting and important, I can offer no other explanation than that suggested by Wood in 1880,* that the Chalky Boulder-clay of the region in question originated as a great mud bank, at first driven before or dragged along by the advancing ice, and afterwards over-ridden by it.

The relation of the three local divisions of the East Anglian drifts proposed by Wood was arrived at by the mapping of the region lying between Yarmouth and Lowestoft, and that of the Flegg Hundred (Fig. 2) to the N. of Yarmouth, in the years 1868–70, and was seen in an interesting exposure at Corton, to the N. of Lowestoft, visited during this day's excursion, where the Chalky Boulder-clay, the Middle Glacial sand, and the Lower Glacial brickearth, the latter containing igneous erratics, were shown in continuous section.†

Attention was drawn to the ravages of sea upon the coast immediately to the south of Lowestoft harbour. Taking advantage of the fact that there is here a prevalent travel of the beach from north to south, groynes are constructed for the purpose of arresting this movement, but unfortunately protection to one locality must always be gained at the expense of another.

An illustration of this is afforded by the harbour works at that place, which have caused a vast and unnecessary accumulation of sand to the north of that place, while the cliffs to the south, robbed of their only reliable defence, are being rapidly destroyed by the sea. Groynes cannot create beach, they can only arrest its natural movement. Nevertheless thousands of pounds are being thrown into the sea near this spot year by year, in the construction of such works, where they can do but little good, and are sometimes swept away almost before they are completed.

On Tuesday, July 14th, a visit was paid to Forncett, nine miles to the S. of Norwich, where the railway cutting already

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* Quar. Jour. Geol. Soc., Vol. xxxvi., p. 487, 1880.

† [There are some facts, however, which seem to indicate that a portion of the Contorted Drift may possibly be contemporaneous with the Chalky Boulder-clay. The author hopes to deal more fully with this part of the subject in a future paper.]

alluded to (Pl. XLVII.) was examined, the identity of the boulder-clay to that of Pakefield being apparent to everyone.* A short stay was made at a well-known section at Tharston Furze Hill, near Forncett, which shows the fine white micaceous sands of the Crag (there unfossiliferous), with pebbly gravel overlying them. resting on the undisturbed surface of the Chalk ; Chalky Boulder-clay on Middle Glacial sand occurs in the immediate vicinity. A large Neocomian boulder was noticed by the road-side near this pit.

From Tharston the party was driven to Wymondham, on the old turnpike from Norwich to London, and eight miles S.W. from the former, where some extensive excavations in "Cannon Shot" gravel, like that of Mousehold Heath (Pl. XLVI.), were examined. At Wymondham, however, and in the surrounding district, these gravels rest upon Chalky Boulder-clay. They are almost entirely composed of flint, but in a heap of *rejectamenta* one or two small boulders of dolerite, quartzite, and Carboniferous Limestone, and one of rhomb-porphyry, were found.

Taking the old coach road to Norwich, a slight detour was made to Cringleford, a picturesque village on the river Yare, for the purpose of examining the writer's collection of Miocene and Pliocene fossils. At this spot, moreover, evidence of the existence of Chalky Boulder-clay beneath the alluvium and the palæolithic gravels of the shallow valley of the Yare, and of the occupation of the latter by ice, during the Upper Glacial period. was pointed out.

Here the excursion terminated, and the writer took leave of his Yorkshire friends, who had proved themselves the most pleasant of comrades and the most courteous of critics.

Forsan et haec olim meminisse juvabit.

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* Sections of boulder-clay of similar character to that of Forncett and Pakefield occur in the region intervening between these two places.

Photographed by Godfrey Bingley, Headingley, Leeds.

SECTION OF THE CANNON-SHOT GRAVELS OF MOUSEHOLD HEATH, TO THE NORTH OF NORWICH.

THE PLEISTOCENE DEPOSITS OF EAST ANGLIA.

BY F. W. HARMER, F.G.S.

I have the pleasure of exhibiting to-night the first maps of the Glacial deposits of this, or I think of any other district, ever attempted on a similar scale, constructed by the distinguished man with whom I had the privilege of working so long. The first was published by him in 1865, the result of a preliminary examination of East Anglia during several years immediately preceeding; the second was drawn, together with more than a hundred miles of sections, for the meeting of the British Association in Norwich in 1868, and although the survey on which it was founded had not then been completed, it represents generally what I still believe to be the geological structure of this district. The third appeared in 1872, in the "Supplement to the Mollusca of the Crag."* It should not be forgotten that Searles V. Wood, Jun., was a pioneer, and it does his memory no discredit to admit that some of his work may require reconsideration in the light of our present knowledge. Although the Glacial deposits of East Anglia have engaged the attention of geologists for many years, and much has been written thereon, they still present problems waiting solution. I therefore cordially welcome this visit of your Society to Norfolk, and hope that, bringing to the study of our drifts an intimate knowledge of those of other districts, you may be able to throw light on some matters as to which we are still in doubt.

I have been asked to open a discussion on "The relation of the Glacial beds of East Anglia to those of the North of England," but, indeed, as to this, I am more anxious to hear your opinion than to express my own. I have recently published, moreover, a *résumé* of my views on East Anglian geology, which some of you may have read.† Briefly restating my opinion as to the conditions which may have obtained in this region during

* Palæon. Soc., 1872.

† "Sketch of the later Tertiary History of East Anglia." Proc. Geol. Assn., Vol. xvii., p. 416, 1902.

the Pleistocene epoch, I will attempt to deal more fully with some of the points raised in the paper referred to, especially as to the probable origin of the Chalky Boulder-clay, the most important of our more recent deposits. It may be desirable. however, in the first instance, to carry our thoughts back for a moment to the geographical conditions of the district at the period immediately preceding the Glacial epoch.

During the deposition of the oldest of our Pliocene beds. the Coralline Crag, the North Sea seems to have existed as a basin closed to the north, but under the influence of the tidal currents of the English Channel, communicating with the latter by a strait over some part of the south-east of England ; the molluscan fauna of these beds was almost exclusively southern. resembling generally that of the Mediterranean at the present day ; early in the Red Crag period, however, connection with northern seas was opened up, perhaps more or less suddenly, while that with the south was closed by a combined tectonic movement of upheaval and subsidence (apparently continuing into the Pleistocene period), to which I have elsewhere referred.* At a somewhat later stage, northern and Arctic shells invaded the Crag basin in considerable numbers and variety, the southern forms from that time gradually disappearing, while, coincidently, the sea retired towards the north ; by the time the Chillesford stage of the Crag was reached, the molluscan fauna of the German Ocean had acquired a boreal and very recent facies. The southern shore of the Crag basin then lay as far to the north as the north coast of Norfolk, and East Anglia was united to Holland. The Chillesford Clay, an estuarine deposit which can be traced in a sinuous course from Chillesford in Suffolk to Burgh in Norfolk, where, in my opinion, it suddenly disappears. as shown in the sketch-map (Fig. 3), probably represents one of the channels through which, at this time, the Rhine reached the sea.

A slight submergence afterwards permitted the German Ocean to re-invade North-east Norfolk, possibly nearly as far as Norwich, introducing marine beds containing in great abundance

* "The Pliocene Deposits of Holland." Q. J. G. S., Vol. 52, p. 748, 1896.

Photographed by Godfrey Bingley, Headingley, Leeds.

SECTION OF CHALKY BOULDER ON THE GREAT EASTERN RAILWAY, NEAR FORNCETT JUNCTION. A BOULDER OF FOSSILIFEROUS KIMERIDGE SHALE HAS BEEN PLACED AGAINST THE SIDE OF THE CUTTING.

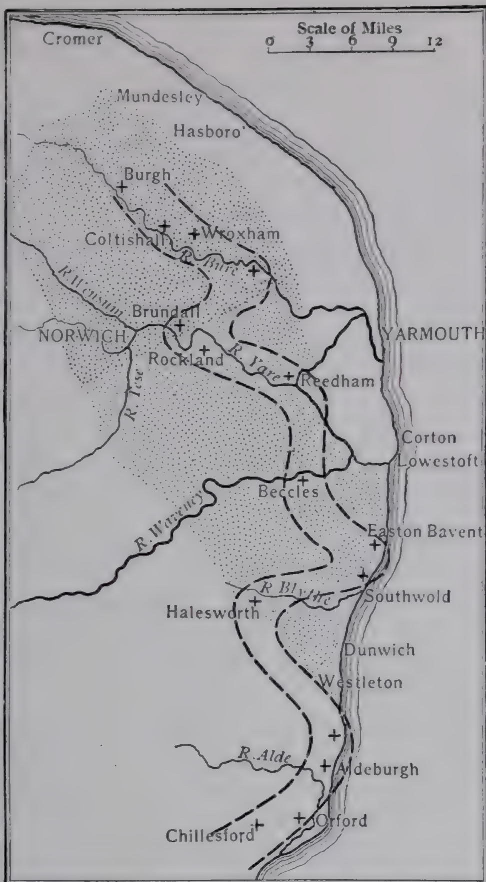

Fig. 3.

MAP SHOWING THE PRINCIPAL EXPOSURES OF THE CHILLESFORD CLAY (+) AND THE PROBABLE COURSE OF ONE OF THE ESTUARIES OF THE RHINE AT THE CHILLESFORD STAGE. (THE DOTTED AREA INDICATES APPROXIMATELY THE DISTRIBUTION OF THE PEBBLY GRAVELS.)

a shell—up to that time unknown in the Crag basin—*Tellina balthica*. Between Coltishall and Wroxham the sea of the *Tellina balthica* Crag seems to have denuded the Chillesford Clay, so that the former deposit rests on the Chalk, such denudation having, in my opinion, destroyed all trace of it further to the north.

There are certain laminated beds at the base of the Cromer cliff section, however, which have been regarded by some observers as of Chillesford age,* and by others as passing horizontally into the Weybourne Crag. I am inclined to agree as to the last point, but not as to the first.

The slight local submergence of the Weybourne stage was followed by another elevation which, during the deposition of the so-called Forest-Bed, reintroduced estuarine conditions into North-east Norfolk, but the estuary of the great southern river then lay somewhat further to the east than during the Chillesford stage.

The Arctic freshwater bed of Mr. Clement Reid, with *Salix polaris* and *Betula nana*, which overlies the Forest-Bed series (the fauna, as well as the flora, of the latter pointing to the existence of a temperate climate), indicates the advent of the Great Ice Age, heralding the approach of the North Sea ice to the Norfolk coast; the arctic freshwater deposit is, in its turn, overlain in the coast section by Glacial deposits, the Cromer Till, and the sands, clays, and gravels of the Contorted Drift. These were placed by Wood in his Lower Glacial division of the East Anglian drifts.† Inland, the Norwich brickearth, into which the Contorted Drift seems to pass horizontally, rests on pebbly flint gravels, the distribution of which is shown in Fig. 3. These may represent the littoral accumulations of the North Sea at this stage, or possibly the detritus of streams issuing from the ice foot, not far distant. Considerable destruction of the Chalk must have been then going on.

We are indebted to Mr. Reid, who spent some years in specially investigating them, for our best account of the Glacial

* Mr. Clement Reid takes this view. In the "Pliocene Deposits of Great Britain," p. 139, 1890, he considers the Weybourne Crag as equivalent to the upper part of the Chillesford Clay. More recently, in the Trans. Norf. and Norw. Nat. Scty., Vol. vii., p. 295, 1902, he shows Chillesford Clay (?) as *resting on* Weybourne Crag. *Tellina balthica*, the characteristic shell of the latter, does not occur, however, at Chillesford.

† Wood's division of the East Anglian drifts into Lower, Middle, and Upper, is probably of local application only.

deposits of the Cromer coast. His Survey Memoir,* and the detailed section of the coast† are so well known, however, that it is not necessary to allude to them here at any length.

The divisions of the coast drifts which Mr. Reid adopts are well shown at the Hasboro' end of the Cliff section. To the north-west of Trimingham the succession cannot be so satisfactorily traced, owing to the disturbed condition of the beds.

As we follow the Contorted Drift from Cromer towards the west it becomes more and more chalky, being over a large area in that region commonly burnt for lime in preference to the Chalk itself. To the east of Weybourne, near Cromer, and further towards the east, it contains enormous masses of Chalk and of chalky marl, see Pl. XLIII. From Cromer and Hasboro' southwards towards Norwich, and south-eastwards towards Yarmouth, the Contorted Drift assumes the character of a red sandy brickearth, occasionally containing minute pellets of chalk, but more frequently without them. Where the clay is of a sandy and comparatively permeable nature, the latter may have been removed by the infiltration of acidulated water. The Lower Glacial clays contain, though not abundantly, erratics of igneous and of other rocks, of moderate size, occasionally attaining a length of three feet or more. They are seldom to be seen *in situ*, though they are frequently met with inland in North-east Norfolk, near farm buildings or by the roadside, possibly representing the accumulation of centuries, a few of them being of Scandinavian origin.‡ A great opportunity presents itself to any petrologist who would set himself seriously to investigate during a summer visit to the Norfolk coast this most important, and until lately, comparatively neglected subject. My friend, Mr. H. B. Muff, of H.M. Geological Survey, was kind enough some time since to examine microscopically a portion of one of the most characteristic erratics of the Lower Glacial brickearth of the Norwich district, and reported that

* Mem. Geol. Survey, Cromer, 1882.

† Horizontal Section, Sheet 127.

‡ Almost all the large erratics of the coast-region are those of igneous rocks.

it was of diabase, suggesting that it may possibly have come from the Whin Sill, which, *a priori*, seems not improbable. Igneous erratics are, however, comparatively rare in the Chalky Boulder-clay of Norfolk and Suffolk (Upper Glacial of Wood). Moreover, shells and broken shell fragments of recent species, such as *Tellina balthica*, are commonly found in the Lower Glacial deposits of the coast. With the exception of two cases given by Mr. H. B. Woodward, for which he suggests a derivative origin from the Crag,* such débris is, as far as I am aware, unknown from the Upper Glacial clay.

It seems improbable to me that the Scandinavian glacier ever touched the Norfolk coast, but its southern termination may have lain at one time at no great distance from it. The Chalk débris of the Lower Glacial clays, some of it from the higher zones of that formation, may have been derived from a local source at no great distance, but the hard Chalk and grey flint came probably from the Wolds, as Mr. Reid also states. In appearance the Lower Glacial clays remind one of those of Yorkshire. The Till at Hasboro' is not unlike the chalky basement clay of Holderness, while the Norwich brickearth resembles the Hessle Clay ; the latter is believed to be newer, however, than these Norfolk drifts. A microscopical comparison of the constituent materials of these deposits would no doubt yield interesting results, and show whether the resemblance is apparent or real.

It is worthy of notice, as Mr. Jukes-Browne has remarked, that most of the clays which cover Holderness and the Lincolnshire marsh-land, and spread on to the Chalk Wolds and over North-east Norfolk, are brown, reddish, or purple, and but seldom contain chalk ; they do not behave as the Chalky Boulder-clay does, in taking its colour and composition from the formations traversed by the ice to which it was due.

Whether or not the Scandinavian ice-stream reached Norfolk at any time, foreign geologists do not doubt that it extended as far as Holland and the north of Germany. Dr. Lorié, of Utrecht, traces what he considers to have been its greatest extension by

* Mem. Geol. Surv., Norwich, p. 115, 1881.

a line running in a S.E.—N.W. direction from Crefeld, by way of Amersfoort and the islands of Urk and Wieringhen, to Texel.* Such a line prolonged still further to the N.W. would cross the North Sea towards the Yorkshire or Lincolnshire coast. It seems more than probable, therefore, that at this period the southern edge of the Scandinavian ice, coalescing with that of the north of England and of Scotland, may have formed a solid barrier, effectually closing the German Ocean to the North. M. Rutot points out that the *Limon Hesbayen*, a deposit which covers with a more or less continuous sheet a considerable region in Belgium and the North of France, stops suddenly *at a point where it attains its greatest thickness*, along a line roughly parallel to what he believes to have been the southern limit of the Scandinavian glacier, and at a distance from it of a few kilometres only.† These facts seem to support the view taken by Belt many years ago that the drainage of the Rhine and its affluents, then flowing, I think, in greater volume than now, at any rate during summer, arrested to the north by an impenetrable wall, formed a great ice- and land-locked lake.‡ The waters of this lake, gradually acquiring a level higher and still higher, might eventually have forced for themselves an outlet into the English Channel; draining the lake by their escape, arresting the further deposition of brickearth, and reintroducing marine currents from the south into the North Sea, they would have altered the character of the sediment accumulating in the Anglo-Belgian basin. The Lower Glacial brickearths, which from the coast southwards to Norwich and beyond are unstratified, seem to be represented in South Norfolk and the northern part of Suffolk by finely laminated clays, as at Boyland Hall, three miles east of Forncett Junction, Diss, Woolpit near Bury St. Edmunds, and elsewhere. While therefore the former may indicate the morainic accumulation of the North Sea ice, the

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* *Le Rhin et le Glacier Scandinave Quaternaire.* Bull. Soc. Belge de Géol. Tome xvi., p. 129, 1902.

† *Comparaison du Quaternaire de Belgique au Glaciaire de l'Europe Centrale.* Bull. Soc. Belge de Géol. Tome xiii., p. 307, 1899.

‡ Nature, Vol. x., p. 25, 1874. See also Quart. Journ. of Science, 1874, p. 440.

latter may be the sedimentary deposits of an extra-glacial lake.

The facts here given may possibly throw some light, however, on one of the most interesting problems of East Anglian geology.

The Lower Glacial beds of the country to the north of Norwich are overlain by a great sheet of sand (Middle Glacial), which forms heaths immediately to the north of that city. The Chalky Boulder-clay of East Suffolk and South-east Norfolk (Upper Glacial), on the other hand, is underlain by a similar deposit, which extends southwards into Essex, though it becomes more gravelly in that direction. It differs from the sporadic masses of sand associated with the glacial clays of the North of England, in forming a more or less persistent deposit, and occupying generally a definite horizon. In our survey of East Anglia, Wood and I found no difficulty in mapping it over an extended area.* Its stratigraphical position is shown in Fig. 2, a map of the Flegg Hundred, near Yarmouth, where these sands rest on the Lower Glacial brickearth, and are overlain by the Chalky Boulder-clay.

The Middle Glacial sands attain in places a considerable thickness, nearly 70 feet in Mid-Norfolk, and more than 50 feet in East Suffolk, and are often much false-bedded.

At a number of localities near Yarmouth, they were found to contain fossils, many of them boreal or Arctic, the fauna having at the same time a decidedly recent facies, *Tellina balthica*, the characteristic shell of the latest zone of the Crag and of the Lower Glacial beds, being one of the most common species.† With hardly an exception the mollusca of the Weybourne Crag have been found also in the Middle Glacial sands. Twelve species of marine Ostracoda, which Messrs. Brady, Crosskey, and Robertson considered to be generally of an Arctic character, were also obtained from the same deposits.‡

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* See our Map published in the Supp. to the Mollusca of the Crag, Pal. Soc., 1872, and afterwards in Q. J. G. S., Vol. lii., Pl. XXXV.

† About 100 species of mollusca are known from the Middle Glacial sands; a list of the more important is given in my paper in the Proc. Geol. Assn., Vol. xvii., p. 460, 1902.

‡ Pal. Soc., 1874, p. 103.

With these recent and boreal shells, the kind of fauna one might expect to meet with in an East Anglian bed of Glacial age, Wood and I found, however, a few specimens, most of them small and some very fragile, of southern and extinct species which had been common in the North Sea during earlier and middle Crag times, but had died out there, as far as we know, long before the Pleistocene period. To explain this anomaly it has been suggested that such forms had been derived from some older Crag deposits. No evidence has ever been offered for this view, however, and I have elsewhere given the reasons why I am unable to accept it.*

If, as before urged, the area now under discussion was occupied during the deposition of the Contorted Drift of Cromer and the country to the south of it by a basin, from which tidal currents were excluded, closed to the north by ice and to the south by the land barrier which came into existence early in the Red Crag period, beds of laminated, or quasi-stratified brickearth might accumulate in it, but it is difficult to see how a great sheet of false-bedded sand and gravel, such as that of the Middle Glacial of the eastern part of Norfolk and Suffolk, which, moreover, seems to be of marine origin, could have done so.† The Middle Glacial sands, though intercalated between deposits of a highly glacial character, give no indication of the existence of ice, either floating or otherwise, in the area just named at this period.‡

If, as already suggested, a breach in the south-western boundary of the supposed extra-glacial lake was at this time opened, and tidal currents from the south were reintroduced, the latter might have brought with them a few specimens of some small and fragile mollusca, which had till then lingered on in the English Channel, though they had long ceased to inhabit the North Sea. A similar difference now exists between the molluscan fauna of the eastern and southern coasts of England, which are

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* Loc. cit., p. 461.

† Further to the south-west the gravel and sand of the Middle Glacial were, no doubt, due to streams issuing from the inland ice.

‡ In the western part of the East Anglian area covered by it, however, the Chalky Boulder-clay is, in places, interstratified with sand or gravel.

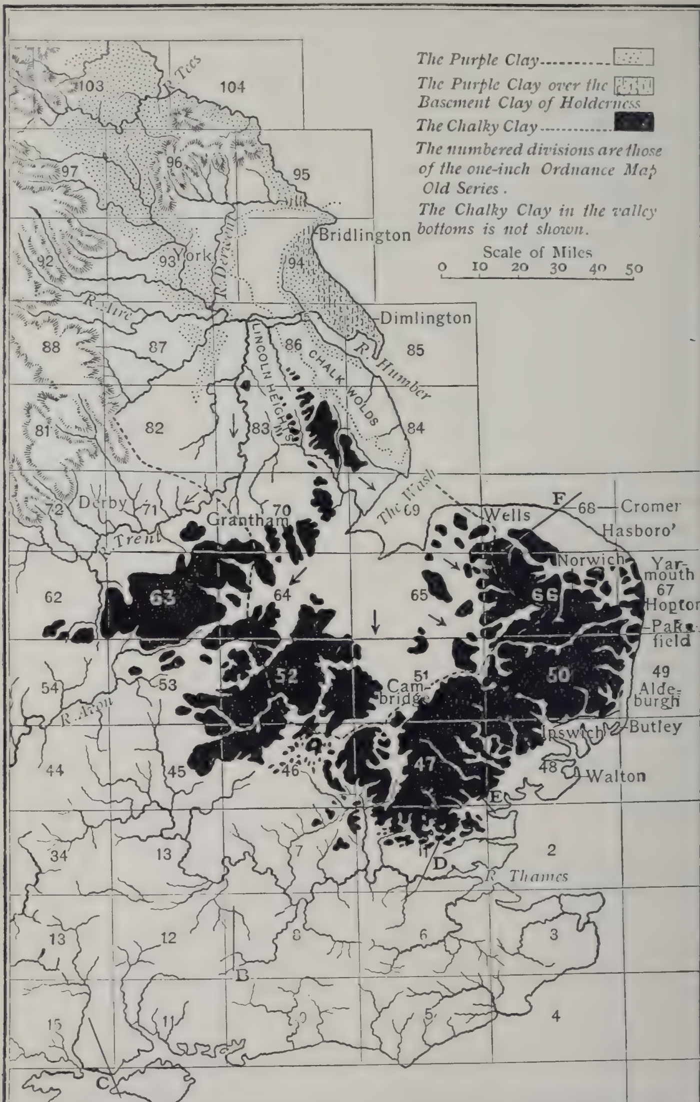

Fig. 4.

MAP SHOWING THE DISTRIBUTION OF THE PURPLE AND CHALKY BOULDER CLAYS OF THE EAST OF ENGLAND. THE ARROWS REPRESENT THE SUGGESTED DIRECTION OF THE ICE-FLOW.

not to any extent connected by tidal currents. Of 33 British shells found near the former, which range into Arctic seas, only five were known to J. Gwyn Jeffreys from the English Channel, while of 45 southern species occurring in the latter, he records only 14 from the shores of the North Sea.

The map (Fig. 4), copied from one published by S. V. Wood, Jun., in 1880,* will explain the distribution, and, possibly, the origin of the Chalky Boulder-clay. Its entire absence from the north-east corner of Norfolk shows that the ice to which it was due did not enter East Anglia from that direction. Some geologists consider that it came through the gap in the Chalk escarpment now forming the Wash, fanning out from the great depression of the Fens in all directions, but no evidence in favour of this view has been offered at present.† It does not seem to me probable that the North Sea ice could have passed through the comparatively narrow neck of the Wash gap in sufficient volume and thickness to have enabled it to travel 60 miles in one direction, towards Leicester, in Sheet 63 (Fig. 4), reaching there a height of 730 feet above Ordnance Datum, and in another, at an equal distance from the Wash, to climb the Chalk escarpment near Royston (Sheet 51), and to heap up its moraine upon it to an elevation of more than 500 feet above the level of the Fens.

I hope, in a future paper, to deal more fully with this question, as well as with the probable origin of the great glacier which spread its moraine over such an enormous area. However, the comparatively low-lying area, now forming the Fen basin, may have been filled with ice, it was, I have little doubt, from thence as a centre that the Chalky Boulder-clay travelled to the east coast in one direction, to the brow of the Thames Valley in another, and into Bedfordshire in a third. Reference to the map (Fig. 4) will show that it extends further from the Fens in some districts than it does in others, and this, I think, can be

* The Newer Pliocene Period in England. Quart. Journ. Geol. Soc., Vol. xxxvi., Pl. XX.

† As far as the district to the east of the Lincolnshire Wolds is concerned, the evidence shows that the ice moved from north to south, and not northwards from the Fens.

satisfactorily explained. The Chalk escarpment, which runs southwards for about 20 miles from near Hunstanton, at the north-west angle of Norfolk, presents, as a rule, a more or less abrupt face towards the west. Where the Chalk outcrop crosses the southern part of Sheet 65 and the northern part of Sheet 51, however, that is, between Swaffham and Newmarket, the line of the escarpment is broken, the N.—S. alignment of the outcrop is interrupted, and pushed back some miles to the east in the form of a bay.

From this area a shallow trough cut out of the Chalk, the lowest part of which does not exceed 50 feet above sea-level, extends from the Fens eastwards, its bottom forming an inclined plane, gradually ascending in the first instance from west to east. Although this depression was no doubt deepened and widened during the Glacial epoch, conditions more or less similar to those of the present had been established there previously to the Chalky Boulder-clay period, as it is occupied by that deposit. Through this gap in the Chalk range, and along this easy gradient, partly the cause and partly the effect of its movement, the ice poured from the Fens in greater volume than over any other part of the counties of Norfolk and Suffolk, as is shown by the fact that it carried its moraine across Sheets 50 and 66 towards Yarmouth, nearly twice as far from the normal position of the Chalk escarpment, as it did over the region extending from Sheet 51 to Sheet 48 (see Fig. 4). The progress of the ice was checked in the latter case by the Chalk hills to the east of Cambridge. Further to the S.W., as near Royston, the crest of the escarpment is still higher, and this again, together with the high land between Dunstable and Fenny Stratford, obstructed the ice-flow, blocking it out from the southern portion of Sheet 46. Across Sheet 52, however, along the basins of the Ouse and the Nene, following the strike of the Oolitic rocks, the ice travelled a considerable distance to the S.W. beyond Buckingham in one direction, and Northampton in another. The area of Sheet 53 was protected from its incursion by high ground, but owing to the pressure of glaciers descending from the Pennines, boulder-clay was piled upon the still higher region of Sheet 63 to an elevation which, as before stated, exceeds 700 feet (Fig. 4).

Whether or not the origin of lake basins in hard rocks may be ascribed to the excavating power of ice, there can be little doubt that the erosion of soft strata, such as the Oxford and Kimeridge Clays, might have been caused in such a way. It does not seem that the great basin of the Fens had been excavated to its present depth in pre-glacial times.

The existence, moreover, of the immense sheet of boulder-clay which covers East Anglia, composed to a great extent of Oolitic material, suggests the glacial deepening of this remarkable feature in the physiography of Great Britain.

It is difficult to form an estimate as to the average thickness of the Chalky Boulder-clay, which varies very much in different districts, or as to the amount of Cretaceous and Jurassic material it contains, but it is clear that the area covered by it is very much greater than the extent of the region, other than that of the Fen depression, from which, locally, it could have derived, as will be seen at a glance at Fig. 4. Unless we may draw in imagination on the Fen area (which on the map practically coincides with the part left unshaded in Sheets 64, 65, and 51), and that to a very large extent, for the source of the southern portion of the moraine of the "Great Eastern Glacier," it seems difficult to offer any reasonable explanation of the existence of the latter.

The views formerly current as to the post-glacial origin of the valley system of East Anglia cannot, I think, be any longer maintained. In 1866, in a paper communicated to the Geological Society of London,* I called attention to the fact that Chalky Boulder-clay exists within the valley of the Yare, near Norwich, and I afterwards discovered further evidence to show that this and some other East Anglian valleys were in existence in Glacial times.† Since then much further light has been thrown on the question, a similar state of things having been found to exist near the Ipswich Railway Station, for example, where an ice stream, travelling down the valley of the Gipping, has ploughed into the Red Crag, leaving upon its disturbed surface a mass of

* A Third Boulder-clay in Norfolk. Q. J. G. S., Vol. xxiii., p. 87, 1866.

† Q. J. G. S., Vol. xxv., p. 445, 1869.

Chalky Boulder-clay; in that of the Waveney, along the sides of which the latter is found at a lower level than that which it occupies on the plateaux to the north and the south, and in many other places. Mr. Whitaker has, moreover, shown that an old and deep valley, running north and south, and apparently more or less coinciding with that of the Cam, in Sheet 47, is filled with drift, which was found at one place to extend to more than 140 feet below sea level.* Mr. J. Hopkinson, F.G.S., has also instanced a similar case in Bedfordshire, where in the plain at the foot of the Lower Greensand escarpment at Sandy, which latter reaches a height of 120 feet above it, a boring passed through 104 feet of boulder-clay to the Oxford Clay.† These and other similar facts indicate that the conditions of the Yare valley, which I originally thought anomalous, may be more or less typical of the general structure of the district. The "Cannon Shot" gravels of Mousehold Heath, the latest of the Glacial deposits of East Anglia, situated as they are on the brow of the valley 150 feet below, in which Norwich stands, in a position where they could not have been accumulated under present conditions, seem also to support the view that during the latter part of the Upper Glacial period many of the valleys of this region were filled with ice.‡

I offer no apology for treating this subject in a somewhat speculative manner—for indulging in what I hope I may call a "scientific use of the imagination." The collection either of facts, or of fossils, although a duty, often laborious and always useful, is nevertheless not the "whole duty of man." In a study as fascinating as is that of geology, it is not always possible while the hammer is busy to keep the mind at rest. Unless, moreover, we are to be crushed under the weight of our own accumulations, it is necessary to arrange, and from time to time to rearrange, our facts in orderly sequence, asking ourselves constantly what they mean, and, where their meaning is obscure, as is so often the case, to what they seem to point.

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* Q. J. G. S., Vol. xlvi., p. 335, 1890.

† Proc. G. S., No. 767, p. 20, 1902.

‡ As to this, see Proc. Geol. Assn., Vol. 17, p. 471, 1902.

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

Fortunately for one like myself, to whom the exertion of prolonged field work is no longer easy, there is still much to be done in the study. It is gratifying, moreover, to find that this classical and important field of inquiry, that of the later Tertiary History of East Anglia, which for some years has been more or less neglected, is now attracting the attention of a younger generation of geologists, who will bring to it new ideas and new methods of investigation.

P.S.—I take the opportunity of publishing here for the first time a map of the glacial deposits of Lincolnshire and South East Yorkshire, Pl. XLVIII., prepared by Wood for the well-known paper by himself and Mr. Rome on that subject read before the Geological Society of London on November 20th, 1867. I think it will have a historic interest for Yorkshire geologists, as being the earliest of its kind in existence. A few copies of the paper, including the map, were printed at the time for private circulation. The one in my possession, of which this is a copy, was accompanied by a pencil note, in Wood's handwriting, stating that the map had been lithographed by him for publication in the Quarterly Journal, but had been rejected on the ground that it was not sufficiently artistic.

Figures 1 to 4 are reproduced from the Proceedings of the Geologists' Association, Vol. xvii., by kind permission.

PRELIMINARY NOTE ON UPPER COAL MEASURES IN YORKSHIRE.

BY H. CULPIN AND G. GRACE, B.SC.

A cutting made near Cadeby (Conisborough) during the construction of the new Dearne Valley Railway has recently exposed the base of the Permian Limestone lying on Carboniferous shales. At a depth of about ten feet below the Permian, among dark-coloured shales, is a layer of ironstone, about three inches thick, containing shells which have been identified by Mr. H. A. Allen, of the Geological Survey, and confirmed by Dr. Wheelton Hind, as *Anthracomya Phillipsi.*

This is the first time traces of undoubted Upper Coal Measures have been found in the county.

The investigation of the exposure is still in progress, this preliminary note being published at the request of Prof. P. F. Kendall, so that he may make use of the fact in the report on the eastern extension of the Yorkshire Coal-field, which he is preparing for the Royal Commission on Coal Supply.

In Memoriam.

REV. JOHN HAWELL, M.A., F.G.S.

One of the most severe losses that our Society and the cause of geological investigation in Yorkshire have suffered for many years has been sustained by the recent death of the Rev. John Hawell, Vicar of Ingleby Greenhow, who passed away after a period of prolonged weakness on Tuesday, 21st of June.

Mr. Hawell became a member of our Society in the year 1887, and took an active part in its Meetings and Field Excursions. In 1896 he accepted the position of Local Secretary for the Middlesbrough District, a post which carried with it a seat on the Council, but the distance of his home from Leeds, where the Council Meetings are usually held, prevented him from being frequently present at their deliberations.

In July, 1896, Mr. Hawell was one of the leaders of the Field Excursion to the Yorkshire Coast north and south of Whitby, and many of the members will remember the quiet, self-controlled way in which he met the fierce attack made upon him by an irate farmer, near Boulby, as the leader of the army of trespassers. At the General Meeting he exhibited and described a series of glacial boulders found in the parish of Ingleby Greenhow.

During this meeting an interesting find of univalve shells was made by Mrs. Kendall in the Upper Lias of Saltwick Nab. As only two species of Gasteropoda had been found before in the Jet Rock, zone of *Ammonites serpentinus*, though it had been worked with exceptional thoroughness for jet, this find was of much interest, and the new species were described and figured in our Proceedings by Mr. Hawell, by whom they received the names of *Actæonina Kendallii* and *Turbo saltvicensis*.

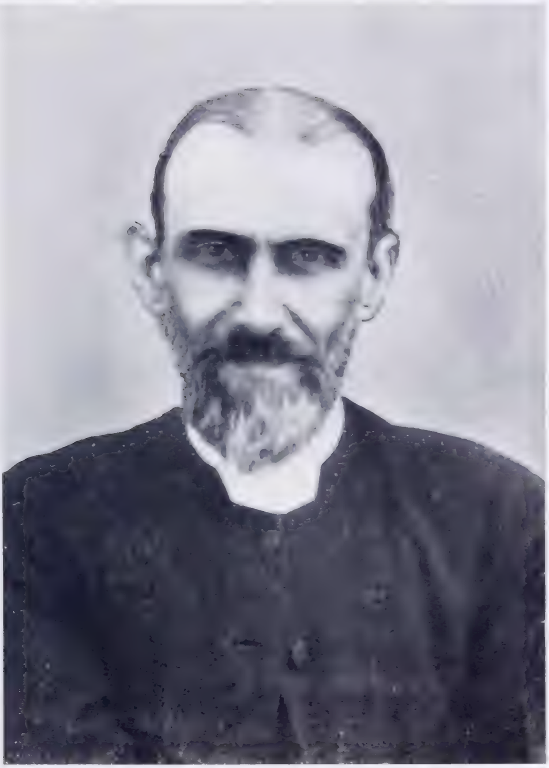
In accordance with his suggestion the summer meeting of our Society in the year 1899 was held at Stokesley, for the examination of parts of the Cleveland Hills adjoining Stokesley, Great Ayton, and Ingleby Greenhow. The Field Excursions were under Mr. Hawell's direction, and his vigorous leadership and genial company will long be remembered by the members present.

At the General Meeting he read a paper on an interesting peat deposit at Stokesley.

Mr. Hawell was a member of the Committee for the Investigation of the Underground Waters of Malham, and took an active part in the earlier work, having charge of one of the stream gauges. He was also much interested in the glacial survey of the Cleveland Hills, carried out by Professor Kendall, and was his companion in many a long tramp over moor and hill.

He had the liveliest interest in Field Geology, and had a keen eye for a fossil as well as a clear grasp of the meaning of the features of a landscape, and his investigations on the glaciology of his own district were well in advance of the general knowledge on that subject. He had made a careful study of the boulders of the parish of Ingleby Greenhow, and Professor Kendall, in his paper on the Glacier Lakes of Cleveland, adds a note in which, speaking of the fact that the immense number of Cheviot rocks in the Yorkshire drift had only been fully recognised by Geologists within the last three or four years (1902), adds :—" It is right that I should add that their abundance in our drift deposits was fully demonstrated by the Rev. John Hawell, in 1887, who reported upon 365 boulders, a large proportion of which were derived from the Cheviots." Also with regard to the overflow-notch from the Ingleby Greenhow glacier-lake into Bilsdale, Professor Kendall, in the same paper says, " This overflow was recognised by the Rev. John Hawell before my survey had extended so far eastward."

The Yorkshire Naturalists' Union also will miss in him a vigorous and inspiring worker. He occupied the position of Secretary and President successively of the Geological Section, and at the time of his death he was Divisional Secretary for the North-east Division of Yorkshire, and was a member of several of the Committees of Research. Mr. Hawell was an interested worker in fields of investigation other than that of Geology. He gave much time and strength to the advancement of the Cleveland Field Naturalists' Club, and was its President for several years. He was Editor of the Club's Proceedings, and contributed many interesting and valuable papers on various features of the Natural History of North-east Yorkshire. One



Sincerely Yours
John Hawell

of the latest pieces of his work was the investigation of the fossil plants from the Lower Oolites of Redcar. These were described in a communication to the *Naturalist*, and one of the new species was named *Dictyozamites Hawellii*, by Dr. Seward, of Cambridge, to whom the specimens were submitted—a well-deserved compliment to a zealous investigator. Of his connection with the Cleveland Club and the stimulus he gave to its operations, Dr. W. Y. Veitch, of Middlesbrough, writes :—" The Rev. John Hawell was the most enthusiastic and genial naturalist it has been my pleasure to meet. He was equally keen in the field of botanical and entomological research, or on the water for what could be found in our dredging expeditions, being ubiquitous in his cheerful help. I first made his acquaintance at one of those meetings, which, needless to say, quickly ripened into a close friendship. His chief delight, however, was in geological work, and the prospect of a find always called forth his energy. He acquired a good scientific library cognate to his work, and a large collection of geological specimens from all quarters of the globe, being in correspondence with geologists of many nationalities. These, with characteristic generosity, he bequeathed to the Cleveland Naturalists' Club and the Dorman Memorial Museum at Middlesbrough, for the benefit of the people of that town."

In addition to his devotion to the Natural Sciences he was keenly interested in the local antiquities, folk-lore, and kindred subjects, and he edited the Ingleby Greenhow Parish Registers, 1539–1800, and the Stokesley Parish Register, 1571–1750, for the Yorkshire Parish Register Society.

Those who have had the pleasure of many a long day's tramp in his company and who have shared the privilege of intimate intercourse with him, will not soon lose the memory of his bright and friendly presence and the infectious enthusiasm of his companionship.

The portrait (Pl. XLIX.) is an enlargement of portion of a group taken by Mr. Godfrey Bingley at the Yorkshire Naturalists' Union Excursion to Brimham Rocks on September 24th, 1902.

W. Lower Carter.

SECRETARY'S REPORT, 1903.

During the year the affairs of the Society have gone on prosperously, and some satisfactory work has been accomplished.

The First General Meeting was held at Leeds, and was associated with a visit to the Leeds Museum to hear a Lecture by Mr. Henry Crowther, F.R.M.S., to children of the elementary schools on "The Marvels of Bird Life." A Field Excursion was also taken to the Meanwood Valley under the leadership of the Hon. Secretary, when the Elland Flagstones were examined in the Scott Hall quarries at Potternewton, and the Ganister Beds at Messrs. B. Rowley & Co.'s quarry on Meanwood Road. In the latter a mid-valley thrust fault was well shown, and an interesting deposit of stony clay overlying the Ganister beds was examined.

At the General Meeting, under the presidency of Mr. James E. Bedford, F.G.S., papers were read by Messrs. H. B. Muff, B.A., F.G.S., and Albert Jowett, B.Sc., on "The Glaciation of the Keighley and Bradford District;" and on "The Faulting of the Ganister Beds in the Meanwood Valley and the Associated Stony Clay," by the Rev. W. Lower Carter, M.A., F.G.S. The papers were followed by vigorous discussions, which were continued to a late hour.

The Second General Meeting and Field Excursion were held at Horton-in-Ribblesdale, on April 24th and 25th. On Friday, April 24th, Mr. J. H. Howarth, F.G.S., was the leader, and conducted the party to the Carboniferous Limestone quarry near Horton Station, where the Lower Carboniferous beds were well exposed, and the underlying slates and grits seen. A traverse was then made to Crag Hill, where the Coniston grits were seen thrown up by an anticlinal. The associated beds of the Coniston Limestone were searched for fossils, but few were found, including a few fragments of trilobites and corals. The party then continued their route to Arco Wood quarries, where splendid sections of the junction of the Silurian grits and slates, with the basement beds of the Carboniferous Limestone were seen. At this point the basement conglomerate is entirely absent.

After luncheon the slopes of Moughton were ascended, and a fine view obtained of the surrounding country as far as Morecambe Bay. The extensive limestone clints were examined, and a visit paid to the head of Crummack Dale, where the springs which break out at the valley end have worn back the limestone into an abrupt scarp.

At the General Meeting, under the presidency of Mr. Wm. Simpson, F.G.S., an address on "The Geology of Ingleborough" was given by Mr. J. H. Howarth, F.G.S., and Mr. A. R. Dwerryhouse, M.Sc., F.G.S., Secretary of the British Association "Committee for the Investigation of the Underground Waters of North West Yorkshire," described the recent work done in tracing the streams on the eastern slope of Ingleborough, and the survey of underground channels connected with Alum Pot. A resolution was passed expressing deep regret at the sudden death of Mr. James Bedford, of Leeds, who had been a member of the Society for 28 years. A meeting of the Underground Waters' Committee was also held, at which arrangements for continuing the investigations were made.

On Saturday morning, April 25th, an enlarged party, under the leadership of Mr. A. R. Dwerryhouse, M.Sc., F.G.S., devoted themselves to the examination of the underground passages running towards Alum Pot. Long Churn was descended by the aid of ladders and lamps, and its passages explored until a glimpse could be obtained of the light entering the precipitous Alum Pot. After luncheon the party descended the hill to Selside, and visited a curious hollow called Footnaw's Hole, which acts as a relief for the underground waters coming from Alum Pot when there is heavy rainfall on the fells. Following the dry channel by which the overflow from Footnaw's Hole is discharged into the Ribble, that river was forded and a visit paid to Turn Dub, an oval pool on the east bank of the Ribble, from which a stream constantly flows, though no inflow of water is seen. By means of fluorescein put in at Long Churn, and reappearing at Footnaw's Hole, and then at Turn Dub, the connection of these holes with Alum Pot had been established. The slow passage of the coloured water, which took thirteen days to make the journey underground of one and a half miles, and the passage of this water under the River Ribble by a natural syphon of limestone under boulder-clay, were interesting facts brought out by the investigation. It was resolved to obtain permission from the landowner to put down two bore-holes in the flat surrounding Turn Dub, to ascertain the thickness of the boulder-clay.

The Third General Meeting was held at Cromer on Friday, July 10th, and was associated with an extended Field Excursion from July 9th to 14th, in the neighbourhood of Cromer and Norwich, under the leadership of Mr. F. W. Harmer, F.G.S., by whom a complete account of the investigations has been written and is published in this part of the Proceedings.

The Underground Waters' Committee has had two meetings during the year, and has continued its investigations on the springs, pot-holes, and channels on the slopes of Simon's Fell above Selside, and the openings at Footnaw's Hole and Turn Dub. At the Southport meeting of the British Association, Mr. A. R. Dwerryhouse, M.Sc., F.G.S., presented the report of the year's work, which was received by the Geological Section with much interest, and the balance of the grant was allowed to be retained for the completion of the investigations.

Our Society was again recognised as one of the Corresponding Societies of the British Association, and Mr. Percy F. Kendall, F.G.S., was appointed delegate to the Corresponding Societies' Committee at the Southport meeting.

The Rev. W. Lower Carter, M.A., F.G.S., was appointed Representative Governor of the Yorkshire College.

The Council have heard with satisfaction that Mr. P. F. Kendall, F.G.S., has been elected a member of the Council of the Geological Society, and that two members of our Society, the Rev. W. Lower Carter, M.A., F.G.S., and Mr. J. Lomas, F.G.S., were chosen secretaries of Section C at the Southport meeting of the British Association.

The number of members given in last year's report is 185. During the year fourteen new members have been elected, two of them being life members. Two of our members have been removed by death—Mr. James Bedford, of Leeds, a respected and valued member for 28 years; and Mr. Adam Millward, of Harrogate. Eight members have resigned, and four have had their names removed as defaulters. This leaves the membership at the same total as before, the gains exactly balancing the losses.

The Council have arranged for a General Meeting at Leeds in February, at which A. W. Rowe, Esq., M.B., F.G.S., of Margate, has been invited to deliver a lecture on "The Yorkshire Chalk." The suggestions for the other General Meetings and Field Excursions were (1) Sedbergh, (2) Bury or Blackburn, and (3) the Annual Meeting at York.

Our Proceedings have been forwarded to the following Libraries and Scientific Societies in exchange for their publications :—

British Museum, Copyright Office.
British Museum (Natural History).
British Association.
Patent Office Library, London.
Royal Dublin Society.
Royal Geographical Society.
Royal Society of Edinburgh.
Royal Physical Society of Edinburgh.
Royal Society of Tasmania.
Royal Society of New South Wales.
Australian Museum, Sydney, N.S.W.
Department of Mines, Sydney, N.S.W.
Australian Association for the Advancement of Science, Sydney, N.S.W.
Department of Mines, Adelaide, South Australia.
Geological Society of Australasia, Melbourne, Victoria.
Nova Scotian Institute of Science.
Natural History Society of New Brunswick.
Royal Institution of Cornwall, Truro.
Royal Geological Society of Cornwall, Penzance.
Bristol Naturalists' Society.
Birmingham Natural History and Philosophical Society.
Cambridge Philosophical Society.
Essex Naturalists' Field Club.
Edinburgh Geological Society.
Geological Association, London.
Geological Society of London.
Hertfordshire Natural History Society, Watford.

Leeds Philosophical and Literary Society.

Leeds Geological Association.

Liverpool Geological Society.

Liverpool Geological Association.

Hampshire Field Club.

Hull Geological Society.

Hull Scientific and Field Naturalists' Club.

Manchester Geological Society.

Manchester Geographical Society.

Manchester Literary and Philosophical Society.

North of England Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne.

Nottingham Naturalists' Society.

Rochdale Literary and Scientific Society.

Southport Society of Natural Science.

Warwickshire Natural History and Topographical Society.

University Library, Cambridge.

University Library, Glasgow.

Bodleian Library, Oxford.

Radcliffe Library, Oxford.

Yorkshire Naturalists' Union.

Yorkshire Philosophical Society, York.

American Philosophical Society, Philadelphia, U.S.A.

American Museum of Natural History, New York, U.S.A.

Academy of Natural Sciences, Philadelphia, U.S.A.

Academy of Sciences, St. Louis, Mo., U.S.A.

Brooklyn Institute of Arts and Sciences, N.Y.

Boston Society of Natural History, Boston, U.S.A.

Rochester Academy of Sciences, Rochester, N.Y.

Kansas University, Lawrence, Kansas.

Wisconsin Geological and Natural History Survey, Madison, Wis., U.S.A.

Geological Survey of Minnesota, Minneapolis, Minn., U.S.A.

California State Mining Bureau, San Francisco.

Chicago Academy of Sciences.

Maryland Geological Survey, John Hopkins University, Baltimore, U.S.A.

Museum of Comparative Zoology at Harvard College, Cambridge, Mass.

New York Academy of Sciences, New York.

United States Geological Survey, Washington, D.C.

United States National Museum, Washington, D.C,

Elisha Mitchell Scientific Society, University of N. Carolina, Chapel Hill, U.S.A.

Meriden Scientific Association, Meriden, Conn., U.S.A.
New York State Library, Albany, U.S.A.
Wagner Free Institute of Science, Philadelphia, U.S.A.
Wisconsin Academy of Sciences, Arts, and Letters.
Smithsonian Institution, Washington, D.C.
L'Academie Royale Suedoise des Sciences, Stockholm.
Societé Imperiale Mineralogique de St. Petersburg.
Societé Imperiale des Naturalistes, Moscow.
Comité Geologique de la Russie, St. Petersburg.
Instituto Geologico de Mexico.
Sociedad Cientifica "Antonio Alzate," Mexico City.
Naturhistorischen Hofmuseum, Wien, Austria.
Societé d'Emulation d'Abbeville, Abbeville.
L'Academie Royale des Sciences et des Lettres de Danemark, Copenhague.
Royal University of Norway, Kristiania.
Kaiserliche Leopold-Carol. Deutsche Akademie der Naturforscher, Halle-a-Saale.
Geological Institution, Royal University Library, Upsala.
Imperial University of Tokyo, Japan.
Museu Nacional de Rio de Janeiro.

W. LOWER CARTER.

THE YORKSHIRE GEOLOGICAL AND POLYTECHNIC SOCIETY.

Statement of Receipts and Expenditure, 1st November, 1902, to 1st November, 1903.

REVENUE ACCOUNT.

Dr. — **Expenditure.**

	Expenditure	£	s.	d.
1903.				
Oct. 29	To Meetings and Excursions	10	5	2
	,, Printing Proceedings (Chorley & Pickersgill)	92	3	6
	,, Printing Circulars, Programmes, etc. ...	10	7	10
	,, Hon. Secretary's Postages and Petty Cash...	9	9	10
	,, Geologists' Association, for Electros... ...	0	8	0
	,, Year Book of Scientific Societies	0	7	6
	,, Cheque Book	0	3	0
	,, Balance in Bank	15	0	1
		£138	4	11

Cr. — **Receipts.**

	Receipts	£	s.	d.
1902.				
Oct. 31	By Balance in Bank	15	8	10
1903.				
Oct. 29	By Subscriptions	83	4	0
	,, Life Members' Subscriptions transferred from Capital A/c	18	18	0
	,, Sales of Proceedings	9	2	3
	,, Halifax Corporation Interest...	11	11	10
		£138	4	11

CAPITAL ACCOUNT.

		£	s.	d.
1903.				
Oct. 29	To Interest on Invested Funds transferred to Revenue A/c	11	11	10
	,, Life Subscriptions transferred to Revenue A/c	18	18	0
	,, Balance invested with Halifax Corporation	350	0	0
		£380	9	10

		£	s.	d.
1903.				
Oct. 29	By Balance Invested with Halifax Corporation	350	0	0
	,, Interest on above	11	11	10
	,, Life Subscriptions...	18	18	0
		£380	9	10

Halifax, October 26th, 1903.

Duly audited, compared with vouchers and receipts, and found correct.

WM. SIMPSON, *Auditor.*

J. H. HOWARTH,
Hon. Treasurer.

RECORDS OF MEETINGS.

Council Meeting, Philosophical Hall, Leeds, March 19th, 1903.

Chairman :—Mr. J. E. Bedford.

Present :—Messrs. F. W. Branson, W. Ackroyd, J. T. Atkinson, E. Hawksworth, W. Simpson, J. E. Wilson, C. W. Fennell, P. F. Kendall, J. H. Howarth, and Revs. J. Hawell and W. L. Carter (Hon. Sec.).

The minutes of the previous Council Meeting were read and confirmed.

Letters regretting absence were read from the Revs. E. M. Cole and C. T. Pratt, Messrs. E. D. Wellburn, F. F. Walton, J. W. Stather, W. Gregson, and G. Bingley.

Prof. P. F. Kendall, F.G.S., was appointed delegate to the Sanitary Institute (Bradford Congress), and to the British Association Corresponding Societies Committee at the Southport meeting.

The Rev. W. Lower Carter was appointed representative Governor of the Yorkshire College. The Secretary reported that Prof. P. F. Kendall had been elected a member of the Council of the Geological Society. A resolution of congratulation was adopted by the Council.

The Secretary reported that he and Mr. J. Lomas had been appointed Secretaries of the Geological Section of the British Association for the Southport meeting.

General Meetings and Field Excursions :—

(1) Cromer.—A letter was read from Mr. F. W. Harmer, F.G.S., expressing his satisfaction that the Society was arranging to visit East Anglia, and offering to aid them in any way. It was resolved, after some discussion, that the date be July 10th to 14th, and that Mr. Harmer be the leader.

(2) Horton-in-Ribblesdale.—The date was fixed for April 24th and 25th, Mr. J. H. Howarth to lead a party for the examination of the flanks of Moughton on Friday, and Mr. A. R. Dwerryhouse to lead the excursion on Saturday for the study of the underground water system around Alum Pot.

(3) Hull.—The Secretary was instructed to arrange for the Annual General Meeting in conjunction with the Hull Local Secretary.

The following accounts were passed for payment :—

	£	s.	d.
Chorley & Pickersgill (Proceedings) ..	81	7	10
Griffin (Year Book of Scientific Societies)	0	7	6
F. Carter (Circulars and Stationery) ..	4	10	0
	£86	5	4

The Secretary read a circular *re* Palæontologica Universalis, a publication for the registering and full description of type specimens. It was resolved to recommend the publication to the Leeds Reference Library.

The Secretary read a letter from Mr. Davies Sherburn, of the British Museum (Natural History), asking for information about the process blocks illustrating our Proceedings ; and one from the Philosophical Society of Cambridge asking for a set of our Proceedings. It was resolved that a complete set so far as possible should be sent.

The issue of Proceedings, Vol. XV., Part 3, was then considered.

Prof. Kendall reported on the illustrations required for his paper on "The Glacier-Lakes of Cleveland." It was resolved that the paper be suitably and fully illustrated, and that the Editors be authorised to go to £25 for this purpose.

General Meeting and Field Excursion, Leeds, March 19th, 1903.

A party was led by the Rev. W. Lower Carter to examine the Elland Flagstones at Potternewton, and the Ganister Quarry in the Meanwood Valley.

The members attended a lecture by Mr. Henry Crowther, F.R.M.S., at the Philosophical Hall, to the Scholars of the Leeds Elementary Schools, on "The Marvels of Bird Life."

The General Meeting was held at the Church Institute, Mr. J. E. Bedford, F.G.S., in the chair.

The following new members were elected :—

Mr. J. P. Lawrence, A.M.I.C.E., Knaresborough.
Mr. Amos Chippendale, Harrogate.
Mr. A. H. Davis, M.A., Ilkley.
Mr. E. Naylor, Bradford.

The Chairman delivered an address.

A paper was read on "The Glaciation of the Bradford and Keighley District" by Messrs. H. Brantford Muff, B.A., F.G.S., and A. Jowett, B.Sc., illustrated by a large map and lantern slides.

A discussion followed, in which Messrs. R. Law, J. E. Bedford, W. L. Carter, C. W. Fennell, P. F. Kendall, and Rev. J. Hawell took part. Mr. Muff replied.

A paper on "The Faulting of the Ganister Beds in the Meanwood Valley, and the Overlying Stony Clay," was read by the Rev. W. Lower Carter, M.A., F.G.S., and illustrated by lantern slides.

A discussion followed, in which Messrs. J. E. Bedford, P. F. Kendall, H. B. Muff, A. Jowett, and Rev. J. Hawell took part. Mr. Carter replied.

General Meeting and Field Excursion, Horton-in-Ribblesdale, April 24th and 25th, 1903.

Chairman :—Mr. William Simpson, F.G.S.

Friday, April 24th.—The party, led by Mr. J. H. Howarth, F.G.S., visited the lime quarries at Horton Station, and examined the underlying Silurian grit which is worked for road metal.

Making their way along the eastern slope of Moughton, a search was made for fossils at Crag Hill, and the unconformity at Arco Wood Quarry was examined. The return journey was taken over the limestone clints of Moughton to the head of Crummack Dale, and the magnificent views were much enjoyed.

The General Meeting was held after dinner at the Golden Lion Hotel, Horton-in-Ribblesdale.

The following new members were elected :—

Mr. Arthur Walter Rowe, M.S., M.B., M.R.C.S., F.G.S., Margate.
Mr. Edward Theodore Ingham, J.P., Mirfield.
Mr. John William Farrah, Harrogate.

The Chairman delivered an address.

An address was delivered by Mr. J. H. Howarth, F.G.S., on "Ingleborough."

An account of the recent investigations of the underground waters of the eastern slopes of Ingleborough was given by Mr. Arthur R. Dwerryhouse, M.Sc., F.G.S.

A resolution of deep regret at the sudden death of Mr. James Bedford, of Leeds, who had been a member of the Society since 1875, and of sympathy with his family, was passed unanimously.

The above papers were followed by a meeting of the Underground Waters Committee,

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Meeting of the Underground Waters Committee, Golden Lion Hotel, Horton-in-Ribblesdale, April 24th, 1903.

Chairman :—Mr. W. Simpson, F.G.S.

Present :—Messrs. A. R. Dwerryhouse, J. H. Howarth, F. W. Branson, and the Revs. C. T. Pratt, J. Hawell, and W. L. Carter (Secretary).

The minutes of the previous meeting were read and confirmed.

Mr. Dwerryhouse reported that Mr. Ashley had left Leeds, and therefore he was unable to continue the survey of Long Churn. It was resolved to pay the out-of-pocket expenses of an assistant to enable Mr. Dwerryhouse to complete the survey.

It was agreed that efforts should be made to complete the investigation of Ingleborough this summer so as to present a complete report to the B.A. Meeting at Southport.

It was agreed to inspect Turn Dub on Saturday, in order to determine on the spot where the bore-holes should be put down.

General Meeting and Field Excursion, Cromer and Norwich, July 9th to 14th, 1903.

July 9th.—Under the leadership of Mr. F. W. Harmer, F.G.S., the party visited North Walsham Church and viewed the Paston Monument. A wagonette then conveyed the members to Hasbro', where a large boulder of laurvikite was noted. The cliff-sections from Hasbro' to Trimingham were examined. At the base was a purplish boulder-clay, sandy in texture, and enclosing many shell fragments and small boulders. This was overlaid by beds of fine silt, bent into folds, and filling hollows in the till. Over this came an upper till rich in chalk fragments.

July 10th.—A wagonette was taken to Weybourne, where the shelly sand known as the Weybourne Crag was examined. The contorted Cromer Drift was well seen in fine sections, and the Forest Bed Series was exposed at the base of the cliff and on the shore at several points.

The General Meeting was held at the Tucker's Royal Hotel, Cromer, under the chairmanship of Mr. Godfrey Bingley.

The following new members were elected :—

Mr. Robert B. Beverley, Wakefield.
Mr. Richard Balderstone Cragg, Skipton.
Mr. William Ackroyd, Leeds.
Mr. Peter Whalley, Colne.

The Secretary exhibited a chart of the Coal Measures of North Staffordshire, with their characteristic fossils, prepared by Dr. Wheelton Hind, and presented by him.

The Society not having any room where it could be usefully displayed, it was resolved to offer the chart to Prof. Kendall to be hung in the Lecture Room at the Yorkshire College. Prof. Kendall suitably acknowledged the gift.

A paper was read by Mr. F. W. Harmer, F.G.S., on " The Pleistocene Deposits of East Anglia."

A discussion followed, in which Messrs. P. F. Kendall, W. L. Carter, C. W. Fennell, and Rev. C. T. Pratt took part.

The meeting closed with hearty votes of thanks to the Chairman and to the leader of the Excursions and reader of the paper. Mr. Bingley and Mr. Harmer responded.

July 11th.—The train was taken to Norwich, and the headquarters was fixed at the Royal Hotel.

The deposits in the neighbourhood of Norwich were examined. including the Chalk, Norwich Crag, and glacial beds. Many important erratics were found which had not been previously recognised so far south, e.g., rhomb-porphyry, Shap granite, and rocks from the Cheviots and the Lowlands of Scotland.

July 13th.—The party went by train to Lowestoft and examined the cliffs from Kessingland to Lowestoft and Corton. The glacial deposits proved of great interest, and the identity of the contents of the Chalky Boulder-clay at Pakefield and in Mid-Norfolk was established. The interception of the beach material, travelling from the north, by the harbour works at Lowestoft had clearly a disastrous effect on the coast to the south of the town, which had been almost entirely denuded of the protecting gravel.

July 14th.—The party visited sections on the Great Eastern Railway and studied the constituents of the Chalky Boulder-clay at Fornsett. Here the clay was composed largely of Kimeridge shale mingled with chalk. The shale was much less ground than at Lowestoft. The most noteworthy boulders were of chalk and flint, resembling those of Lincolnshire and Yorkshire with some Spilsby Sandstone and Red Chalk. A few igneous rocks were found, including chiefly dolerites. In a great gravel pit at Wymondham two specimens of rhomb-porphyry were found. At Hethersett, near Cringleford, Chalky Boulder-clay was seen to be destitute of the Kimeridge Clay fragments which characterise it further south.

The party were entertained to tea by Mr. and Mrs. Harmer, at Oakland House, and the host's fine collection of fossils was examined. Hearty thanks were accorded to Mr. and Mrs. Harmer for their kindness.

Meeting of the Underground Waters Committee, Leeds, 3rd September, 1903.

Chairman :—Prof. P. F. Kendall.

Present:—Messrs. W. Ackroyd, F. Swann, A. R. Dwerryhouse, S. W. Cuttriss, C. W. Fennell, J. H. Howarth, J. J. Wilkinson, G. Bingley, and Revs. E. Jones and W. L. Carter (Secretary).

The minutes of the previous Committee Meeting were read and confirmed.

Letters of regret for absence were read from Messrs. W. Morrison and W. Simpson.

Mr. Dwerryhouse read the report for presentation to the B.A. Meeting at Southport. It detailed the results of the investigation of the streams north of Alum Pot, and round the shoulder of Ingleborough into Chapel-le-Dale. The stream from the shooting-box, though dosed with 2 lbs. of fluorescein, had not yet yielded any indication of its course after sinking. Fluorescein put into Grey Wife Sike had been found to emerge at Moses' Well. Owing to the proprietor of the land about Turn Dub being in Africa, it had not been possible to obtain permission to put down the bore-holes.

The report was adopted with the hearty thanks of the Committee to Mr. Dwerryhouse for the great care, amount of time and labour he had expended on the investigation.

Mr. Dwerryhouse presented a financial statement showing a balance in hand of £32 15s. 1d. It was resolved that application should be made to the British Association for the reappointment of the B.A. Committee for another year, with the use of the unexpended balance. It was suggested that Hunt Pot and Hull Pot should be investigated during the visits of the Committee to Ingleborough next year.

Mr. Dwerryhouse presented a plan of underground channels above Alum Pot, and reported that he was preparing a report on the joints of the limestone and their relation to the underground passages, but that it was not yet completed.

A conversation was entered into as to the advisability of the Y. G. and P. Society attempting further investigations in association with a B.A. Committee. Several suggestions were made, but the further consideration of the matter was postponed until next year.

Council Meeting, Philosophical Hall, Leeds, 24th September, 1903.

Chairman :—Prof. P. F. Kendall.

Present :—Messrs. G. Bingley, E. Hawksworth, F. W. Branson, A. R. Dwerryhouse, J. H. Howarth, W. Ackroyd, J. W. Stather, F. F. Walton, J. E. Bedford, C. W. Fennell, J. J. Wilkinson, Revs. C. T. Pratt and W. L. Carter (Secretary).

The minutes of the preceding meeting were read and confirmed.

Letters regretting non-attendance were read from Rev. E. Maule Cole, and Messrs. W. Simpson and J. T. Atkinson.

Annual Meeting at Hull.—Subject to Dr. Tempest Anderson being able to lecture on the West Indian eruptions, October 22nd was selected for the meeting; the place and time to be decided by the Secretary in conference with the Local Secretary. A visit to be paid to the Hull Municipal Museum, and an excursion to be arranged for Friday to Sewerby.

The following papers were accepted:—

Mr. G. W. Lamplugh, on "Land Shells in the Sewerby Beds."

Messrs. Crofts and Kendall, on "Borings in the East Riding."

Underground Waters Report by Mr. Dwerryhouse.

The Secretary presented the annual report.

Nominations were made for the Officers and Council, and the Secretary was instructed to send out a nomination form, as before, to each member.

Meetings and Field Excursions for 1904.—Suggestions were made for a meeting at Leeds in February, with a lecture by Mr. Arthur W. Rowe, F.G.S.; a General Meeting at Bury or Blackburn; and a General Meeting at Sedbergh; the Annual Meeting to be at York.

An excursion to the Isle of Man was suggested for 1905.

The appointment of a Committee to co-operate with the B.A. Committee for the investigation of the beds at Kermington, the Mammaliferous deposits of the Vale of York, and the Sewerby beds, was discussed, and the matter was adjourned until the next Council Meeting. Correspondence was read between the Secretary, Mr. J. J. Wilkinson, and the Grassington Parish Council with respect to the condition and custody of the "Finds" collected from Grassington Moor by the Society's efforts, and entrusted to the care of the Parish Council. The following resolution was adopted:—"That the Council, having heard the correspondence with the Grassington Parish Council, is glad to learn that the cases of "Finds" are now being arranged, but would remind the Parish Council that these relics were handed over to their custody on the condition that they were properly housed in a public room, and they trust that the Council will, as soon as possible, have them replaced in the Town Hall buildings."

The following account was passed for payment :—

F. Carter, Circulars and Stationery .. £5 17 10

Annual General Meeting, Grosvenor Hotel, Hull, 29th October, 1903.

A visit was paid to the Municipal Museum, where the members were met by Mr. T. Sheppard, F.G.S., Curator, who described the chief objects of interest.

The Annual Meeting was held under the presidency of Mr. F. Fielder Walton, F.G.S., L.R.C.P.

Letters of regret for absence were read from Lord Ripon, Rev. C. T. Pratt, and Messrs. E. T. Ingham, E. Hawksworth, and J. E. Wilson.

The Hon. Secretary read an abstract of the Annual Report.

The Treasurer, Mr. J. H. Howarth, presented the Financial Statement.

Resolution 1 :—"That the Report and Balance Sheet as presented be adopted and printed in the Proceedings." Proposed by Rev. E. Maule Cole, seconded by Mr. J. T. Atkinson, and carried.

Resolution 2 :—"That the best thanks of the Society be given to the President, Vice-Presidents, Officers, and Members of Council for their conduct of the affairs of the Society during the past year, and that they be re-elected to serve for another year." Proposed by Mr. J. H. Lofthouse, seconded by Mr. J. Norton Dickons, and carried.

Mr. John Carlton, of Hull, was elected a member of the Society.

The Chairman delivered an address.

The following papers were then read :—

"The Pre-Glacial Surface of Holderness," by Messrs. P. F. Kendall and W. H. Crofts.

"The Diversion of the River Don," by the Rev. W. Lower Carter, M.A., F.G.S.

"Land Shells in the Infra-Glacial Chalk Rubble at Sewerby, near Bridlington," by Mr. G. W. Lamplugh, F.G.S.

"Report of the Underground Waters of Ingleborough," by Mr. A. R. Dwerryhouse, M.Sc., F.G.S.

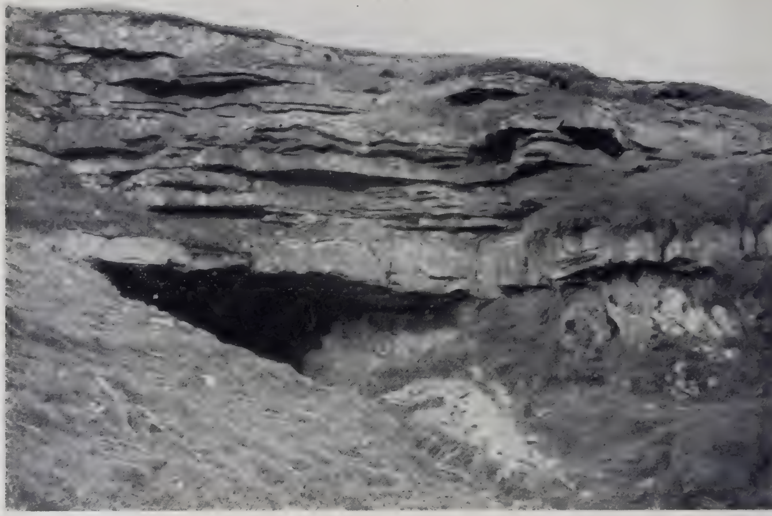
A Lecture was given by Dr. Tempest Anderson on "The West Indian Eruptions," illustrated by a fine series of lantern slides.

Resolution 3 :—"That the best thanks of the Society be given to Mr. F. Fielder Walton, F.G.S., for presiding, to the readers of the papers, to Mr. J. W. Stather, the leader of the excursion, to Mr. Thomas Sheppard, the Curator of the Museum, and to Dr. Tempest Anderson for his interesting Lecture." Proposed by Mr. Godfrey Bingley, seconded by Mr. McTurk, and carried.

The Chairman briefly responded.

The members and their friends dined together at the Grosvenor Hotel, under the presidency of Mr. F. Fielder Walton, F.G.S.

October 30th.—A Field Excursion was taken to Flamborough Head, under the leadership of Mr. J. W. Stather, F.G.S. The party went by train to Bridlington, and by wagonette to the Flamborough Lighthouse. The glacial beds on the top of the cliff and the blow-hole were examined, and a descent made to the beach at High Stacks. A fine boulder of augite syenite (laurvikite) was found on the beach. The cliff sections were examined as far as Sewerby. Several considerable falls of rock were noted. The section at the buried cliff was found to be much obscured by rain-wash, but the rubbly and sandy beds were clearly seen.



Photographed by Godfrey Bingley, Headingley.

Fig. 1.

UNCONFORMITY BETWEEN ORDOVICIAN AND MOUNTAIN LIMESTONE, CHAPEL-LE-DALE.

Photographed by Godfrey Bingley, Headingley.

Fig. 2.

INGLETON "GRANITE" QUARRY, CHAPEL-LE-DALE, GREEN SLATE SERIES.

Vol. XV.] [Part III.

PROCEEDINGS

OF THE

YORKSHIRE GEOLOGICAL SOCIETY.

Edited by W. LOWER CARTER, M.A., F.G.S.,

and WILLIAM CASH, F.G.S.

1905.

INGLEBOROUGH.

PART II. STRATIGRAPHY—*continued*.*

BY T. McKENNY HUGHES, M.A., F.R.S., F.G.S., WOODWARDIAN PROFESSOR OF GEOLOGY IN THE UNIVERSITY OF CAMBRIDGE.

THE SILURIAN ROCKS OF INGLEBOROUGH.

In the year 1822 two men might have been seen walking and talking together over Kirkby Moor. The elder was a plain, matter-of-fact sort of man of about 54 years of age. We should soon learn that he was not a native of our northern counties, but one born and bred in the Midlands. We should not be long with him before we found out that he was a clear-headed, far-sighted observer of men and of nature. He had the quiet, determined bearing of one who had gone through struggles in early life in which a man of less tenacity of purpose would have succumbed. He had, however, gained the great object of his life ; had earned an honourable independence and achieved a great scientific success. He had constructed, single-handed, a geological map of England, and had determined the great principles

* Continued from Proc. Yorks. Geol. and Polytec. Soc., Vol. xiv., p. 343.

of the succession of strata and their identification by means of the included organic remains, for this was William Smith.

The younger was a man of about 37, a brilliant scholar of great academic distinction and full of imagination. Intellectual vigour that loved to grapple with the most difficult problems of the universe flashed out of his dark eyes and rippled in his rapid, racy speech, which was redolent of his home in the Yorkshire dales, for this was Adam Sedgwick.

Nine years later, from the Presidential Chair of the Geological Society, Sedgwick gave William Smith the title by which he will be ever fondly known—"the father of English geology." In 1822,* however, William Smith was working out the details of the geology of England for his county maps, and Sedgwick, who had recently been appointed to the Chair of Geology in his University, was also constructing a map of the district, and collecting fossils with which to illustrate his lectures. Here on Kirkby Moor they met for the first time, and together hammered out fossils from the Kirkby Moor flags, the highest beds of the Silurian seen in the north of England. The name Silurian was then unknown, and all these rocks were included in the great Greywacke formation.

This is the record of very early work on the sub-division of the rocks afterwards known as Silurian. Sedgwick soon lectured upon the result of these researches, and used them in the syllabus which he published for the use of his class.

I will not now reopen the old question of how much credit is due to him in the establishment of the position and divisions of the Silurian rocks, but I do think that this strong society of Yorkshiremen should see to it and protect the memory of one of Yorkshire's noblest sons. I have given my opinion of his work both in the pages of your journal, November 28th, 1883, and in the life of Sedgwick, written in conjunction with Mr. Clarke (see vol. i., pp. 284-297, 529-539; vol. ii., 502-563).

Now let us pass on to consider what parts of the Silurian rocks are exposed among the roots of Ingleborough, what is

* Third letter from Sedgwick to Wordsworth on the Geology of the Lake District. See Hudson's Guide to the English Lakes, 5th ed., 1859, p. 202.

their relation to the other rocks associated with them, and what are their equivalents elsewhere.

If Sedgwick walked home from Kirkby Moor he crossed the whole of the Silurian, and if he walked from his home in Dent to Ingleborough, he crossed it again, only this time mostly covered by great masses of newer formations, and exposed only in the deep valleys which have been cut down through the Carboniferous rocks. The higher beds of the Silurian are not seen under Ingleborough (Fig. 1), but the lower part of the series is well represented, and we will now consider the place of the Ingleborough Silurian in respect of the phases of sedimentation which have produced important differences in the character of the rocks before we proceed to correlate the beds in detail with those of other areas.

The Conditions which Determined the Character of the Silurian Rocks of Ingleborough.

If you look at the Geological Map of England, you will see from the pattern that there have been great anticlinal and synclinal folds running east and west, that they were repeated in several successive periods, and lastly that there were movements of such a kind that the axes of these folds now slope to the east.

The trough which holds the Culm Measures of Devon passes under the Hampshire Tertiary basin, and the anticlinal of the Bristol Channel is prolonged under the Wealden uplift, while the coal basins of South Wales disappear under the Secondary rocks, and these in turn under the London Tertiary basin which plunges east under the North Sea.

The great bend in the Secondary rocks of the Midlands and East Anglia indicates an uplift which must have affected Mid-Wales, and, as all the other movements of elevation and depression belonging to this system can be shown to have recurred, so we may assume the probability that this also was of various dates.

The Silurian and Bala Beds under Ingleborough are thrown into folds approximately parallel to those to which I have just referred (Fig. 2), and we must therefore inquire whether these facts throw any light on the geology of the district in which we are now specially interested.

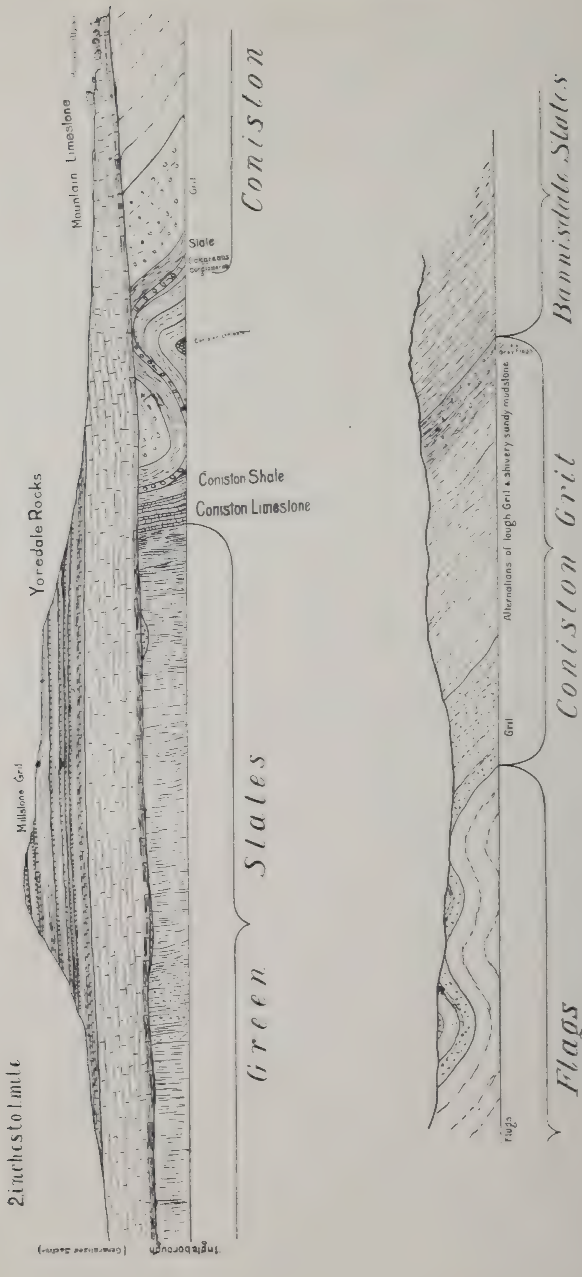


Fig. 1.

GENERALISED SECTION ACROSS INGLEBOROUGH.

There is a cross system of folds running generally N.N.E. and S.S.W., and the intensity of the disturbance increases as we pass across these from east to west, and also as we traverse the various folds from north to south. The upturn on the south rim of the London basin is much more gradual than that seen in the Isle of Wight, and the folds of the South Wales Coal Field are less severe than those found along either the Bristol Channel anticline or among the Coal Measures of Somerset, and far less intense than those seen among the crushed and plicated rocks of Devonshire. These general inferences from observations made over wide areas teach us what we should look out for in examining the details of any similarly folded rocks within the region affected by such movements. One leading fact established by these inquiries is that through Central Wales, across the Midlands and East Anglia to the sea, there was an ancient line of movement which affected the distribution of the Bala and Silurian in Wales, brought Carboniferous and older beds up through the Secondary rocks in the Midlands, and threw the Tertiary beds far out to sea in East Anglia.

We find that towards the close of the epoch represented by the Bala Beds there followed conditions under which sediment free from volcanic material was everywhere spread over the lavas and ashes which form the greater part of that series in North Wales and the Lake District.

Now volcanic outbursts are not the cause, but the consequence, of earth movements, but they may be always regarded as indicating such movements. Therefore we have reason to believe that over the region north of the Mid-Wales uplift the conditions were different not only in respect of the rapidity, extent, and exact age of the earth movements, but also, over considerable areas, in respect of the material of which the sediment was composed. South of the great central uplift the Bala Beds are composed chiefly of mud; while north of it they are made up largely of volcanic material. South of it the Silurian consists of mudstones with important intercalated limestones, which extend over very wide areas considering their small thickness, while north of it the sediment was coarser and has given rise to immense formations of flags and sandstones. The change in conditions has affected also the Carboniferous rocks, but of that anon. Thus we have in the Bala series and in the Silurian a southern and a northern type, according as the deposits were laid down on the south or on the north of the great Mid-Wales axis of earth movement which I have described above.

The Silurian of Ingleborough belongs to the northern type. It is also interesting as being the most easterly exposure, in the north, of rocks of this age, and it may therefore be useful to give a table (p. 360) pointing out as nearly as may be its place in the series with its sub-divisions and their equivalents elsewhere. When the palæontological vernier is applied the general sequence suggested by the succession of beds of different lithological character is well supported. But first of all let us set forth that which can be easily verified, that which can be mapped, that which will enable a student to fix and record the exact horizon in which he may find certain fossils.

As we follow the Bala Beds upwards in ascending section above the Coniston limestone and shale, many stratigraphical and palæontological difficulties present themselves. We find that there must have been some change in the conditions which affected the character of the sediment and favoured the incoming of new forms of life into this area. The fine mud of Ashgill in the Lake District and of Fairy Gill, and many another little known stream north of Ingleborough, was then laid down. This "Ashgill Shale," wherever it has been detected, is in conformable succession to, and is bracketed with, the Bala Beds. It has not, however, been recognised everywhere at the top of the Bala Beds, and it varies in thickness, but we have not yet sufficient data to infer with any confidence whether this is due to original unequal or irregular deposition or to a small unconformity at the base of the Silurian.

The Ashgill Shale is not well developed anywhere under Ingleborough. I did not see anything that I could refer to it at Crag Hill, but it may be detected yet on the lower slopes. The rock immediately beneath the basement bed of the Silurian at Austwick Beck Head is so crushed that recognisable fossils are not likely to be found in it, but there also it would be worth while to make a careful search along the horizon where the Ashgill Shale might be expected across the Crummack valley to the east. Near the waterfall by Wharfe Mill Dam, however, it does seem to be represented by certain black shales cropping out below the conglomerate which here occurs at the base of the Silurian.

A troublesome fossil which occurs in the Ashgill Shale here, but is far more common and well preserved at the same horizon east of Sedbergh, is *Strophomena siluriana*. It is not yet quite clear whether this fossil is confined to the Ashgill Shales, or whether it passes up into the basement bed of the Silurian, but I will postpone the consideration of this point till I come to the Silurian.

General Sketch of the Geographical Distribution of the Silurian Rocks under Ingleborough.

The Silurian rocks of the Ingleborough district roll over in spoon-shaped anticlinals and synclinals, and are exposed in the Crummack valley, in Ribblesdale,* and still further east out of our district. Several of the folds can be identified from one valley to another, so that we can conjecture with great certainty what the character of the surface would be like if we could take away the great tabular masses of Mountain Limestone, such as that of Moughton which covers the Silurian between Ribblesdale and the Crummack valley.

The character of the folds, neglecting minor faults and puckerings, is shown in the ground plan diagram, Fig. 2.† The newest beds, or those marked Ab4, are the tough gritty sandstones seen on the east side of Ribblesdale in Long Lane, south of Studfold, especially near the guide post. This division does not appear again in the Ingleborough area, but there are higher beds of this stage exposed in the wild country known by the appropriate name of Rough Lands, north-east of Great Stainforth.

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* Plate XL., Figs. 1 and 2, Proc. Yorks. Geol. and Polytec. Soc., Vol. xv., Part II.

† This Diagram is reproduced here from Proc. Yorks. Geol. and Polytec. Soc., Vol. xiv., p. 332.

From below these Studfold sandstones the main mass of the Horton Flags, Ac1, creep out, and, attaining a thickness of some 2,000 feet, occupy the whole of the eastern side of the valley as far north as Dove Cote and south nearly as far as Sherwood House. Owing to the rise of the synclinal axis as we follow it to the west, and a higher dip on its northern limb as seen at Arco Wood, the breadth of the mass is reduced under the limestone scar on the west of the Ribble to about three-quarters of a mile as compared with the two miles of ground which it and the overlying Studfold sandstones occupy where they disappear under the Mountain Limestone on the east of the valley. The Horton flags can be traced along the slope below the southern

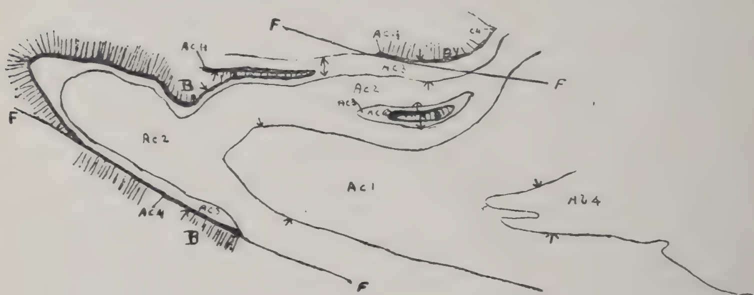

Fig. 2.

GROUND-PLAN SHOWING RELATION OF SILURIAN AND BALA SERIES BENEATH THE CARBONIFEROUS ROCKS.

A. Silurian ... { Ab4, Studfold Sandstone. Ac1, Horton Flags. Ac2, Austwick Grits. Ac3, Pale Slate and Graptolithic Mudstone, with subordinate limestones. Ac4, Basement Bed.

B. Bala Beds.

precipices of Moughton and the tip of the tongue formed by this synclinal is protruded into the Crummack valley from beneath the western cliff of Mountain Limestone immediately below Studrigg Scar.

The Austwick Grits crop out from beneath the Horton Flags. They are about a thousand feet in thickness, and from their massive, tough character and the occurrence in them of subordinate beds of softer material, they always give rise to marked features in the landscape. They can be traced by

Stainforth and Swarth Moor, they form the rugged slopes below the southern scars of Moughton, and they occupy nearly the whole of the floor of the valley of Crummack except a small part of the north end.

Below these grits there is always a roughly-cleaved sandy mudstone, with subordinate grits, to which I have for convenience of reference given the name Austwick Flags. This subdivision, which has a thickness of about 400 feet, varies much in general appearance, according as the cleavage coincides with the bedding or is transverse to it. We observe also considerable differences in composition and texture. There are in it some beds of tough grit, the larger of which give rise to important scenic features, as, for instance, that which, having a thickness of some 60 feet, accounts for the wild rocky scenery in the beck below Capple Bank, or that which, with an apparent thickness of about 20 feet, projects through the soil near the upper end of Moughton Lane. These beds, however, more commonly consist of a soft mudstone splitting by cleavage and joints into small rhomboidal pieces, or readily breaking into slabs on which the bedding is sometimes indicated by faint lines and bands, or yielding rough flags when the bedding and cleavage coincide.

They are best seen along their southern outcrop near Southwaite and along the line of the road from Austwick to Crummack.

The basement bed of the Silurian, i.e., of the Upper Silurian of the Survey, is the most interesting of the whole system. It is everywhere the horizon which presents the greatest difficulties. It is of small thickness, and therefore easily overlooked; it consists of, and occurs among, alternations of deposits of different composition, texture, and structure, which are therefore apt to be either wholly removed or obscured by denudation. It is exceedingly variable, and is therefore difficult of identification where there is not a continuous exposure along which the changes of character may be traced. But it is the most worthy of careful examination, for it is the first accumulation of sediment under the new conditions which set in after the age of volcanic activity had passed away, and the full life of the Bala rocks had given place to a new group, among which very few of the abundant species of the earlier period are to be found.

It may be convenient to give here a tentative correlation of the more conspicuous sub-divisions of the Silurian rocks of Ingleborough, with those of the adjoining area of Sedbergh and the Lake District, and with those of North Wales ; that is to say, with some of the characteristic sections of the "Northern Type" as described above. The "Southern Type" will be referred to where it throws light on special points :—

Ingleborough.	Adjoining District.	North Wales.
Basement Beds of Carboniferous. Unconformity.	Basement Beds of Carboniferous. Unconformity.	Basement Beds of Carboniferous. Unconformity.
	Kirkby Moor Flags.	
	Kendal Beds.	Sandstones.
	Bannisdale Slates.	Llansannan Shales.
	Firbank Limestones.	
	Tebay Mudstones.	Grove Mudstones.
	How Gill Beds.	Bodfari Beds.
	Acidaspis Zone.	Acidaspis Zone.
Grits of Rough Lands.	Winder Grit.	
Studfold Sandstone.	Helm Knot Sandstone.	Moelfammau Sandstone.
Horton Flags.	Upper Coniston Flags.	Nantglyn Flags.
Austwick Grit.	Middle Coniston Flags.	Caer Drewyn Grit.
Austwick Flags.	Lower Coniston Flags.	Fenyglog Flags.
Pale Slates (and red shale).	Pale Slates.	Pale Slates.
Graptolithic Mudstone. (with Spengill Limestone and Zone of *Phacops elegans*).	Graptolithic Mudstone. (with Spengill Limestone).	Graptolithic Mudstones.
Conglomerate or Calcareous Grit.	Paste Rock or Conglomerate.	Conglomerate Calcareous Grit or Pisolitic Limestone.

Basement Bed of Silurian.

On some part of the upper Bala Beds there is generally a thin conglomerate, represented sometimes by only a few pebbles occurring here and there, or it may be in the place of the conglomerate a banded rock more or less gritty or more or less felspathic, but containing some material not derived from the immediately underlying series. It is often rich in fossils, and the lenticular fossiliferous bands indicate the incoming of forms of life over an area where they have not been similarly associated before. In one place you find a great number of one form, in another adjoining area the fossils numerically characteristic are different.

Let us for a moment consider the conditions under which basement beds are formed. If a limestone is being wasted away, by various denuding agents, and thus furnishes the material for a new series of deposits, we may have in the case of rapid accumulation a limestone breccia, or, under slower action, may have a conglomerate, or, perhaps, only the insoluble residuum as a red clay or loam. Or if, as in the case of the Upper Chalk, it contains flints, we may have a bed of flint pebbles, as in so many of our Tertiary rocks, or a bed of subangular gravel.

The occurrence, therefore, of fragments of the harder parts of the underlying rocks, sporadically or in patches, over any area, points to the lapse of time to allow for the upheaval of the older rocks and for their subsequent denudation and the carrying away and sorting of the material over adjoining areas.

But the division between the newer and older series is not always easy to trace, because there is not everywhere a conspicuous conglomerate, and the newer mud is very like the older from which it was derived. That is the difficulty we have to face in tracing the boundary between the Silurian and the Bala Beds. But still with care it can be done.

If the older beds have been violently disturbed before the deposition of the newer series of which we are examining the base, there is seldom any difficulty in tracing the basement bed. It is transgressive across the upturned edges of the older rocks, and as it is made up of fragments of the different strata of which they are composed, we can sometimes infer the direction in which the material has travelled, and even find evidence as to the mode of transport. We can measure the amount of rock removed from the ancient surface before the deposition of the newer beds, and get a measure of the interval that elapsed between the commencement of the uplift and consequent destruction of the older beds, and the deposition of the basement bed of the newer. The greater this lapse of time the greater as a rule is the change in the forms of life brought about by the change of conditions.

But if the movements have been of much less intensity and shorter duration, if the old sea bottom with the deposits of ages heaped up over it has not been upheaved above sea level over the whole area, but yet changes affecting the currents and the forms of life have been setting in, so that a different sediment is carried over the area, and conditions become unsuitable for most of the old forms of life, and readjustments of shore lines and of depths have encouraged new forms to migrate into the area, then it is often difficult to draw a line exactly showing where the new order of things commenced. The newer and older beds are, at any rate as far as can be seen within small distances, parallel. If great deposits of as yet unconsolidated mud or sand are being wasted away, the resorted material is mud or sand, and there will be little difference between the new deposit and that on which it rested. Yet even when such uniform and gentle movements are taking place over one area, if there is evidence that changes of such a character as to introduce a new facies have taken place, we may be pretty sure that the movements have not been quite uniform, and that denudation has every here and there been exposing new rocks which in time get buried up, and thus fragments of the harder parts are drifted over the old surface, and occur either sporadically or in small banks of gravel, which form lenticular beds along the base of the new series.

We have on Ingleborough excellent examples of both these conditions. The conspicuous unconformity at the base of the Carboniferous rocks of which I shall have to speak more in detail by and by, is an example of enormous lapse of time, of tremendous uplifting, folding, and denudation of the older rocks before the basement bed of the newer was laid down upon them. It rarely rests on the same stratum of the underlying series for more than a few feet. But in the case of the basement bed of the Silurian, we have an example of the second kind. It is difficult to find, difficult to trace when found, and rests generally upon a bed in the older series, which, with small variations in thickness and lithological details, evidently represented approximately the same horizon at the top of the Bala Beds, and it succeeds well-known beds of that formation which can be correlated over wide areas.

I have already pointed out, on a plan (Fig. 2), where the basement bed of the Silurian is seen among the roots of Ingleborough, and where it and the overlying parts of the series would probably be found if we could peel off all the post Silurian strata of the district. In explaining the relations of the uppermost Bala, I have also given diagrammatic sections showing the mode of occurrence of the basement bed of the overlying Silurian.

In Fig. 3 and in Fig. 4* the conglomerate " *b* " represents it. About 60 yards north of Dam House Bridge, near Austwick, the faults shown in Figs. 3 and 4 cross the stream at a small angle to the strike of the beds, and somewhat obscure one of the most important sections in the whole district. On the north or downthrow side the basement bed of the Silurian forms a

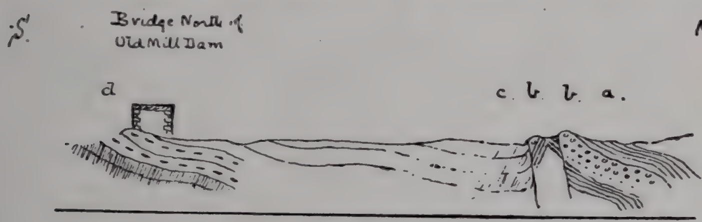

Fig. 3.

a. Striped sandy shale.
b. Conglomerate.
c. Cleaved mudstone.
d. Felspathic ash-like beds, similar to those seen south of the barn in the field on the west.

small cliff running through the little wood on the N.N.W., it is seen in the fields below South-thwaite, and disappears under the Mountain Limestone of Norber.

The basement conglomerate is here thicker and coarser than anywhere else in the district, and might well repay close work. The maximum thickness of the basement conglomerate is about ten feet where the top and bottom can be seen. South of South-thwaite large blocks are seen lying about or collected off the land into heaps, but these do not occur along

* For convenience these Figures are reprinted from Proc. Yorks. Geol. and Polytec. Soc., Vol. xiv., pp. 332, 335, and 336.

the outcrop. It makes no feature where it should cross Moughton Lane, or where it passes under the base of the Mountain Limestone east of Norber, from which we should infer that it probably thins out in this direction also, and is merely a lenticular bed of small extent. It is made up of rolled and angular fragments up to eight or ten inches in diameter, derived largely from the Green Slate Series, the fine felspathic mudstones and finer and coarser grits, conglomerates, and breccias of that series being all represented in the conglomerate. There were also fragments of a rock very similar to some of the beds in the under-

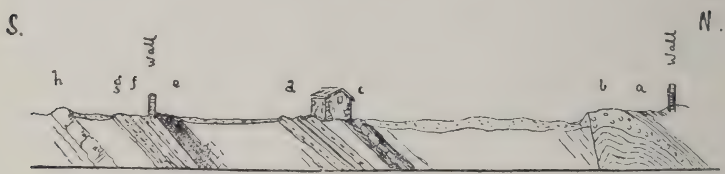

Fig. 4.

a. Striped sandy shale not much cleaved.
b. Conglomerate not well seen in the line of this section.
c. Cleaved shale with subordinate calcareous band.
d. Felspathic ash-like beds and yellow porcellanous rock with subordinate black bands, one very conspicuous. These are probably the beds seen under the bridge.
e. Slate strongly cleaved 70° S.S.W.
f. Felspathic, speckly, ash-like beds exposed at the gate for a horizontal distance of about 8 feet.
g. Very tough, granular, crystalline rock, with small sago-like grains of transparent quartz, about 10 inches seen.
h. Limestone, with a knobbly, irregular surface, about 2 feet seen.

The strike of *e*, *f*, *g*, *h* is clear, but not the dip; indeed, it may be that between this and the barn we have crossed the axis of the fold, and that we are already on the southern limb of the anticlinal.

lying Bala. The matrix was very calcareous, often a coarse crystalline limestone, in which two species of coral *Favosites alveolaris* and *Favosites* (*stenopora*) *fibrosa* were not uncommon. In the included fragments Professor Harkness informed me that a *trinucleus* had been found, but I have been unable to verify this statement, or, indeed, to find any derived fossils.

The first thing to be done is to make a collection of every kind of fragment and every variety of matrix in this conglomerate, and subject them to careful examination, macroscopic, microscopic, and chemical, and to compare them with the rocks of other areas from whose equivalents they may have been derived. The probability is that this conglomerate has been washed down from pre-Carboniferous ranges on the north, running with the strike W.N.W. and E.S.E. As the hade of the fault and the dip of the beds are both to the north, when the angle of dip and the amount of the hade are the same, the same bed lies along the fault as they both rise to the west, but when they are not equal, whichever is the lowest of the two, namely, the hade or the dip, creeps out furthest south, and if they or the slope up the flank of the valley vary, then the relative positions of the fault and of the outcrop of the bed will change accordingly. The variation in the thickness of the bed of conglomerate further complicates the structure, but still its leading features can be made out.

It appears to be a lenticular mass thinning out to the E.S.E. It may be that there was a pre-Silurian protuberance connected with the sharp anticlinal fold seen in the bed of the stream immediately north of the fault. However that may be, the base of the Silurian is here represented by a very thin bed of calcareous mudstone, with a conglomerate made up of small pieces of various felspathic rocks. Above this comes a thin bed of tough, whitish calcareous mudstone full of fragments of trilobites, among which the following species have been detected :—

Phacops elegans, Boec. and Sars.

Cheirurus.

Encrinurus punctatus Brünn.

These are succeeded by blackish, flaggy shales with purple bands, which have yielded some fossils. The limestone may be the equivalent of the limestone of Spengill, near Sedbergh, in the area north of Ingleborough, and both call for work, and would probably repay it.

The distinctive fauna of the Graptolithic Mudstone, or Stockdale Shale, has not been yet detected here.

The basement beds of the Silurian are next seen at Austwick Beck Head (see *d* of section, Fig. 5)*. It is exposed on the

* Reprinted from Proc. Yorks. Geol. and Polytec. Soc., Vol. xiv., p. 338.

northern limb only of the anticlinal, close under the earthy bank on the north side of the stream. As has been pointed out above, one's attention is caught by the conspicuous conglomerate at the base of the Carboniferous, which, owing to the same circumstances that cause the outburst of the springs here, creeps out on to the lower ground over the Bala shales, so that some might give up the search for any other basement bed than that obviously belonging to the Carboniferous, for the basement bed of the Silurian is very thin and obscure. It resembles

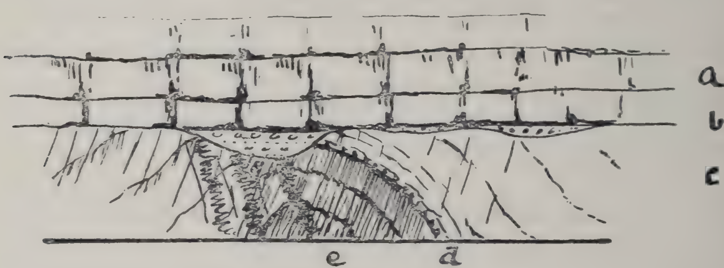

Fig. 5.

DIAGRAM ILLUSTRATING THE MODE OF OCCURRENCE OF THE STRATA AT AUSTWICK BECK HEAD.

a. Mountain Limestone.
b. Basement bed of the Mountain Limestone.
c. Silurian.
d. Basement bed of Silurian.
e. Bala Shale and Limestone.

the bed seen in the stream near Dam House Bridge rather than the coarse conglomerate seen below South-thwaite. No fossils have been recorded from it in this section, nor from the beds associated with it. It is shown in the photograph Plate L.,* where the hammer is laid across its outcrop. The white beds above are the Mountain Limestone, and the Bala Beds are seen in the stream below the hammer. The basement bed of the Silurian is here made up chiefly of the soft schists of the Green Slate Series. From the

* Proc. Yorks. Geol. and Polytec. Soc., Vol. xiv., Part III.

abundance of these in the basement bed of the Carboniferous also, which is well seen on the other side of the stream, nearer the mouth of the keld, it is clear that the Green Slate Series cannot be far off. The matrix of this basement bed of the Silurian is here also rather calcareous, especially in the white band at its base, but as it is composed almost entirely of the soft sandstone beds of the older series, the general appearance of the rock is very different from that seen near Wharfe Mill Dam, where the predominance of hard rocks in the conglomerate makes it stand out, and the number of pebbles of grit and conglomerate, bright with pink orthoclase felspar mixed with various shades of green and grey, give the whole a rich and pleasing colour. But in the section at Austwick Beck Head it is dull coloured and inconspicuous.

The basement bed of the Silurian is again seen in the next valley to the east at Crag Hill, near Horton-in-Ribblesdale. The plan and sections (Figs. 6, 7 and 8)* show the relation of this bed, the grey crystalline limestone (*e*), to those above and below; (*e*) is the band which, starting from the "H" of Crag Hill, is shown lapping round the Bala Beds on the ridge above the farm. It consists of a very tough, coarsely crystalline limestone, very like that which forms the matrix of the thicker part of the conglomerate near Wharfe, and it contains the same two corals, *F. alveolaris* and *F. fibrosa*. It has a mottled darker and lighter grey appearance, both on weathered and newly-fractured surfaces, such as might be due to brecciation in place and subsequent alteration, or to incipient concretionary action. It is quite different from the Bala Limestone which is seen close by, and is a close-textured dark blue grey rock, with abundant fossils, as explained in the previous part. Soft beds probably succeeded it, but they have been cut back by denudation, and their outcrop must be sought in the deep hollow on the north of the ridge. On the top of the anticlinal, at the higher end of the ridge near the foot of the Carboniferous scar, the overlying beds much resemble those which form the base of the Austwick Flags near Wharfe.

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* Reprinted from Proc. Yorks. Geol. and Polytec. Soc., Vol. xiv., p. 340.

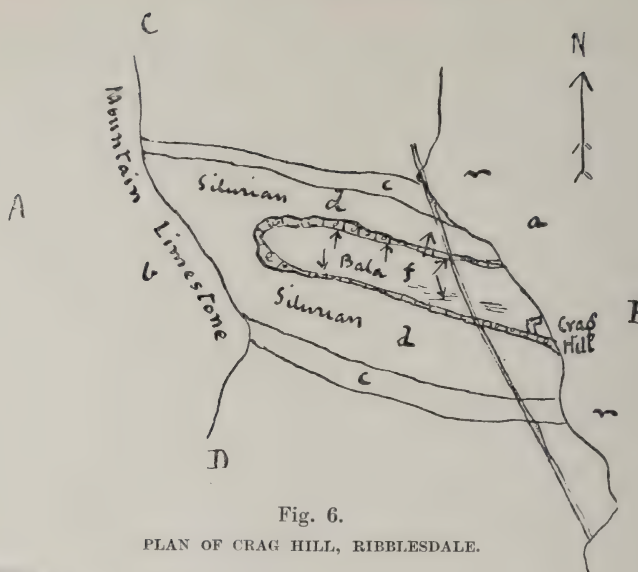


Fig. 6.

PLAN OF CRAG HILL, RIBBLESDALE.

Fig. 7.

SECTION FROM A TO B.

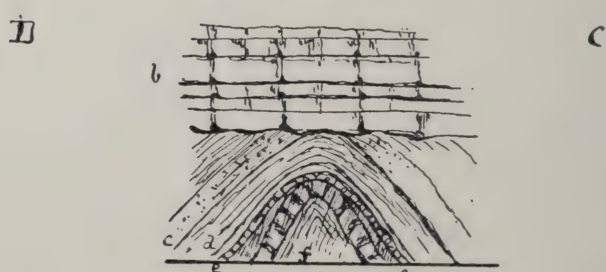


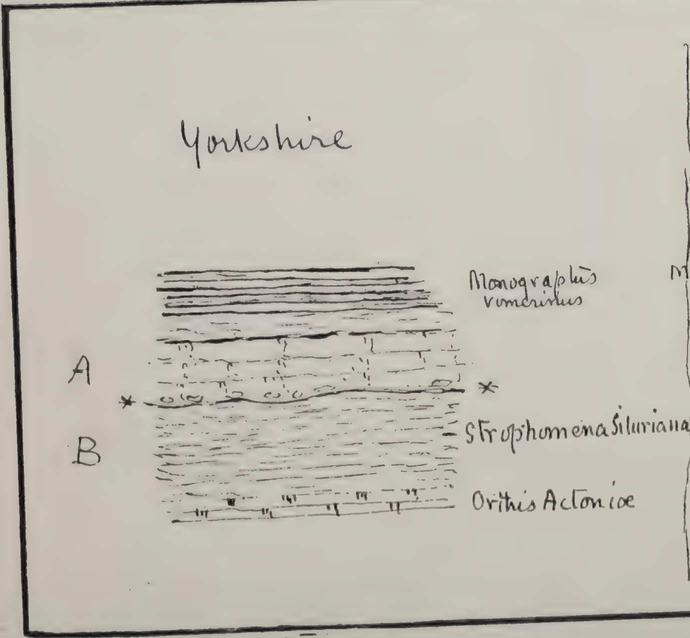
Fig. 8.

SECTION FROM C TO D.

a. Alluvium.
b. Carboniferous Limestone.
c. Base of Austwick Grits.
d. Austwick Flags.
e. Grey Crystalline Mottled Limestone (basement bed of Silurian).
f. Bala Beds.

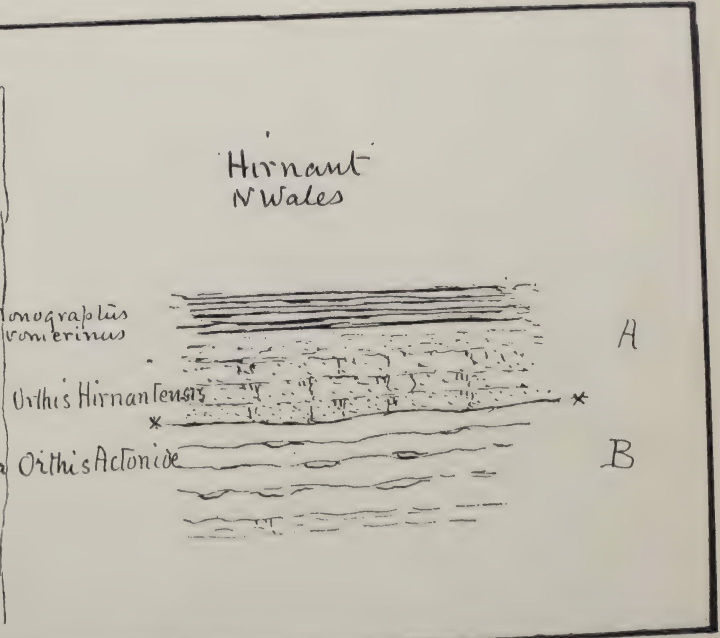
All the varieties of lithological character observed in the basement bed of the Silurian under Ingleborough may be seen in the corresponding position in other districts, especially immediately to the north of Ingleborough, in Hebblethwaite Gill, and other sections in the same district east of Sedbergh. In Skelgill, behind the Bowness Hotel at Windermere, it is represented by a thin, tough calcareous bed, with a few pebbles in it here and there. In North Wales a similar hard banded rock, with a few patches of pebbles, mark the base of the Silurian in Nant Caweddau, near Corwen, and in this the only fossil found was *Favosites alveolaris*. The Hirnant Limestone is the exact counterpart of the crystalline basement limestone at Crag Hill. Tracing the base of the Corwen grit by Cyrnybrain, on the west of the Dee Valley, we find coarse white grits, with *Meristella crassa*, *Petraia subduplicata*, *P. crenulata*, and other fossils, which connect this horizon with the Lower May Hill or Llandovery Beds, which form the base of the Silurian in South Wales. At Blaenycwm, near Llandovery, a similar thin conglomerate forms the basement bed of the Lower Llandovery. With all its palæontological and lithological variations, we have in the Austwick Conglomerate a very persistent horizon represented, and one well worth further close examination.

There is a palæontological question which wants further elucidation. In the description of the fossils of the Hirnant Limestone, McCoy described a flat, finely-ribbed brachiopod, which occurs abundantly at that horizon, as an *Orthis*, and named it *O. Hirnantensis*. When I was tracing the base of the Silurian in the Sedbergh district I found a fossil much resembling McCoy's *O. Hirnantensis* in shape and external markings in the black shales of Fairy Gill and elsewhere in that district. But the mapping led me to assign the beds in which it occurred to a lower horizon than that to which I was inclined to refer the Hirnant Limestone. I had the good fortune to have as my frequent companion in the field the Rev. H. G. Day, the Head Master of the Grammar School, a keen palæontologist, and with him made a large collection from the Fairy Gill shales, and found that the fossil which so strongly resembled McCoy's *Orthis Hirnantensis* had the valves turned over like a *Strophomena*,



Yorkshire
Monograptus vomerinus
A
B
Strophomena Siluriana
Orthis Actoniae

Fig. 9.



Hirnant N Wales
Monograptus vomerinus
Orthis Hirnantensis
Orthis Actoniae
A
B

Fig. 10.

and that it was only where the recurved part was broken away that our fossil could be taken for an *Orthis*. We sent a selection of them to Davidson, who confirmed this view, and named the species *Strophomena siluriana*. When, however, he looked into the matter with a view to his monograph on the Silurian brachiopoda, he was unable to satisfy himself as to McCoy's *Orthis Hirnantensis*, and merely reproduced his figures and description.

In the above sections, Figs. 9 and 10, the asterisks mark what I take to be the base of the Silurian. In the Hirnant section, A3 consists of flags with *Monograptus vomerinus* and but slight difference apparent at their base, except that they are of a paler colour. These pass down into a sandy pisolitic limestone, which weathers into a rusty gingerbread-coloured rock, with fossils abundant, and among them the *Orthis hirnantensis*. This granular bed rests upon a strongly-cleaved schistose rock, with limestone concretions, among which I found *Orthis actoniæ*. In the Yorkshire section, A consists of similar flags to those of the Hirnant Section, with the same fossils, and at its base there are red bands in the pale series, and sometimes a thin dark fossiliferous limestone. All these rest on a coarse light-coloured crystalline limestone, sometimes with few, sometimes with many, included pebbles, but the only fossils are two species of coral, *Favosites alveolaris* and *Favosites fibrosa*. This, in the adjoining district, rests on a dark shale with *Strophomena siluriana*, while *Orthis actoniæ* occurs abundantly lower down.

Now the question is this, should the Hirnant Limestone be bracketed with the Bala Beds, and is McCoy's *Orthis hirnantensis* only a badly-preserved *Strophomena siluriana?* I think that it is not so, but that the relation between the several series is as I have indicated above.

I hope on a future occasion to give a detailed description of the rest of the Silurian Rocks seen under Ingleborough, and to discuss some further palæontological questions connected with them.

ON DIFFERENTIAL EARTH-MOVEMENTS DURING CARBONIFEROUS TIMES, AND THEIR SIGNIFICANCE AS FACTORS IN DETERMINING THE LIMITS OF THE YORKSHIRE, DERBYSHIRE, AND NOTTINGHAMSHIRE COALFIELD.

BY COSMO JOHNS, M.I.MECH.E., F.G.S.

(The substance of this paper was the subject of the introduction to a discussion on " Earth Movements " at the Leeds Meeting of the Yorkshire Geological Society, March 2nd, 1905. It has since been revised.)

CONTENTS.

I.—INTRODUCTION.

The theory generally accepted as explaining the occurrence of Coal Measures in detached basins is that after the deposition of these rocks a series of earth movements, post-Carboniferous in time, took place, certain ridges were upheaved, and after these had suffered denudation the remaining portions of the Coal Measures would survive in the basin-like depressions formed by the upheaved margins. Of late years, however, evidence has been accumulating which seems to suggest that the older theory does not accurately represent the complicated series of earth-movements that were in progress during Carboniferous times, nor the part they played in determining the present limits of the British coalfields. In this paper it is proposed to briefly discuss the effects of these movements so far as the Yorkshire, Derbyshire, and Nottinghamshire coalfield is concerned, and to determine, so far as is possible, their sequence and character. For the sake of brevity the area under discussion will be called the Yorkshire coalfield.

II.—The pre-Carboniferous Floor under Stress.

If we knew more about the structure of the old Silurian floor it is very possible that we should find the present form of the coal basins indicated, and that in no very vague form either. When its various beds were subjected to the tangential stress that marked the post-Silurian era, the stressed rocks found relief in plication and fracture, with the resulting formation of its characteristic ridges and hollows. When equilibrium had been established, it is clear that the more normal phase of earth-movements came into operation, and the Silurian floor became affected by differential subsidence. That it was really a subsidence is indicated by the vast thickness of sediments laid down. That it was differential is evident from the variations in the age and character of the sediments laid down in different areas. It will suffice to mention that in South Wales* there is an uninterrupted sequence of deposits from the base of the Old Red Sandstone to the top of the Coal Measures, while in Yorkshire the Carboniferous basement conglomerate rests on the upturned edges of the truncated Silurian folds. A discussion of other areas would serve to disclose other differences in the rate of subsidence. The chief exposures of pre-Carboniferous rocks in Yorkshire are in the neighbourhood of Ingleborough, and it is suggestive that their strike displays a marked tectonic relationship with the Charnian axis, and this suggests that, like that ancient ridge, the exposures in Yorkshire might be a complex of rocks older than Silurian. The significance of this relationship will be pointed out later. The coming into operation

* A. Strahan. Geology of South Wales Coalfield, Part I., p. 1.

of the Craven faults during the Carboniferous Limestone* period served to sharply differentiate the rocks north and south of the faults, and proving that subsidence was greater in the southern area. It seems established, therefore, that after the Silurian floor had found relief from the tangentive stresses by which it had been affected, it came under the influence of normal gravitational stresses acting in a vertical plane, but differential in their effect on the rate of subsidence.

III.—Datum Lines from which to Measure Vertical Movements.

There is often some difficulty in deciding whether earth-movements in a vertical plane were positive or relative, or even to decide on the direction in which the movement took place, with the result that descriptions of earth-movements are often not so clear as could be desired. When possible, of course, it is desirable to decide positively whether the motion, in the case of vertical movements, was towards or from the geometrical centre of the earth. Lack of data renders this difficult sometimes. The author therefore sought for some datum line in the Coal Measures themselves by which the character and extent of the movements affecting those rocks could be determined. He took the more persistent coal seams, such as the Barnsley and Kents Thick, and assumed, as seems generally accepted,† that they were laid down in marshes or lagoon-like areas, and that during formation they were approximately in a horizontal plane. If this be granted, then we have at our disposal an approximate datum line from which to measure vertical movements. If we take the Barnsley seam, use it as a datum line, and, neglecting the faults, plot down the position which the older seams then occupied, it becomes very evident that sedimentation had been accompanied by differential subsidence, as will be seen on reference to Fig. 4, Plate LI, while several interesting modifications are seen towards the margins.

* R. H. Tiddeman. Brit. Assoc. Rep., 1889, p. 600.

† Strahan. Brit. Assoc. Rep., 1900, p. 746.

IV.—Significance of the Thinning of the Coal Measures Towards the Margins.

That the Coal Measures thin, sometimes with rapidity, towards their margins has long been known. The case of the famous Dudley seam formed by the measures between the coal seams of the South Staffordshire coalfield thinning out to nothing against the Silurian rocks is perhaps the most striking instance. In the Yorkshire coalfield the thinning is very marked towards its southern boundary. We have already seen that the central area was characterised by differential subsidence; if now we consider the southern boundary to have been an axis of relative stability, we are enabled to explain the known facts. This explanation, too, would be in harmony with movements in other portions of the area under discussion, and is clearly brought out in Fig. 3. In other words, the downward movement was less rapid as the margin is approached, and might have been nothing at the axis itself. It is difficult to discover how much further back we must date the limiting action of this ridge, but it is suggestive that in South Wales* it was hinted "that there may be some connection in shape between the present Carboniferous basin and the area of subsidence in which the maximum development of the Carboniferous rocks took place." This would imply that the present configuration of the basin was determined by pre-Carboniferous movements, which we have already seen is rather clearly indicated in the Yorkshire coalfield. The significance of the thinning of the Coal Measures towards their margins lies in the evidence they afford that the present limits of the basins were determined, not by post-Carboniferous upheavals, but by a series of differential movements of inter-Carboniferous age.

V.—Character of Faulting.

In the Yorkshire coalfield the faults are normal ones, that is, they hade to the downthrow side. This of course involves extension of the strata affected, and indicates that there was

* The Geology of the South Wales Coalfield, Part II., p. 19.

an absence of tangential stress such as would be required if marginal ridges had been uplifted. They possess, too, the radial and peripheral characteristics so suggestive of a subsiding area. The almost complete absence of overthrusts and reversed faults in the area is a marked feature; while the fact that so many of the faults were intermittent,* in that, while having a large throw in the Coal Measures, they reappear with a smaller throw in the new rocks above, suggests that careful investigation might, in fact probably would, reveal instances of the faults having been progressive ones during Coal Measure times. This would show itself in a diminished throw in the upper seams. There seems to be some evidence of this, though convincing sections are not available.

VI.—Relative Age of Inception of the Charnian and Market Weighton Axes.

It will be seen from Fig. 4 that the Charnian axis was relatively stable for some time before the Barnsley seam was formed. Its stability was but relative, and at times it partook of the motion of the adjoining area. Its function in determining the limits of the Carboniferous rocks in its direction probably dates back to post-Silurian times. In the case of the Market Weighton axis, it seems to be clear that it was only after the formation of the Barnsley seam that it became stable, for marked thinning only appears after that stage. There is evidence, too, in recent borings, unfortunately not available for publication, along a line normal to the axis, that this condition obtained through Triassic times. The Market Weighton axis therefore came into existence as a line of relative stability after the formation of the Barnsley seam, and is posterior in age to the Charnian axis.

VII.—The Age of the Pennine Range.

The tangential stress that plicated and rolled up the Silurian rocks before the laying down of the Carboniferous basement conglomerate was applied from the east. The tectonic relationship

* Geological Survey, Summary of Progress, 1902, p. 5.

existing between the Charnian axis and these pre-Carboniferous rocks exposed near Ingleborough has been mentioned, so that we may assume the possibility of an extension of the Charnian axis under the Pennines. The fracture of the Silurian floor that caused the Craven faults would destroy the stability of the ridge if it existed, and therefore the absence of any perceptible barrier between the Lancashire and Yorkshire coalfields up to the horizon of the Silkstone coal of Yorkshire (equivalent of the Arley Mine of Lancashire) is not surprising. The correlation of the seams up to this horizon in the North Staffordshire, Lancashire, and Yorkshire coalfields is convincing evidence that the Pennine barrier did not exist in Lower Coal Measure time. There is little or no evidence of thinning in the Middle Coal Measures on the Yorkshire side of the Pennines, but on the Lancashire side there is marked thinning of the Upper Coal Measures against the Pennines. There is additional evidence in the difference between the Permian rocks east and west of the great barrier, while the absence of Upper Coal Measures, of a type comparable to those of North Staffordshire and Lancashire, in the Yorkshire coalfield points distinctly to a barrier between the two great areas of subsidence, and dates the appearance of the Pennine Range at the close of the Middle Coal Measure period. At the same time it is very probable that it exercised some influence between the Silkstone or Arley Mine period and that of the close of the Middle Coal Measures. Great difficulty has been experienced in correlating the seams that lie above the Silkstone or Arley Mine bed in the Yorkshire and Lancashire basins. This might be taken to indicate that the buried pre-Carboniferous ridge was beginning to come into action and acted intermittently during Middle Coal Measure time, at the close of which it became a rigid barrier separating two subsiding areas. It has already been pointed out that there is an absence of evidence of tangential stresses having been applied in the Yorkshire basin during or since Coal Measure time. On the Lancashire side there is positive evidence of a thinning of the Upper Coal Measures towards their eastern margin, while the coal seams themselves are steeply inclined. The inference is that the

Pennine Range is a stable ridge that came into existence at a comparatively late period in Coal Measure time. That it acted as a barrier between two differentially-subsiding areas. The steepness on the Lancashire side is explained by the fact that this area was subsiding faster than the Yorkshire one, and obviates the necessity for calling in the assistance of a thrust from the east to explain the structure. The Pennines may be regarded as a range of the Uinta type,* formed by the coming into action of the deep-buried pre-Carboniferous ridge.

VIII.—Conclusions.

Briefly stated, the conclusions arrived at from the consideration of the limited data available of the tectonic features of the coalfield and its margins are as follows :—

(*a*) The Charnian axis is an ancient ridge of relative stability dating back to at least post-Silurian time.

(*b*) The Market Weighton axis was in existence as a relatively stable anticline during Middle Coal Measure time and soon after the formation of the Barnsley seam.

(*c*) The Pennine Range is of the Uinta type, and the date of its appearance might be fixed not later than the close of the Middle Coal Measure period. The difficulty in correlating the Middle Coal Measure seams on both sides rather suggests that it was exercising some influence a little earlier.

(*d*) The present limits of the Yorkshire, Derbyshire, and Nottinghamshire coalfield were determined, not by post-Carboniferous earth-movements, but as a result of the operation of a sequence of complicated movements commencing with the post-Silurian tangential stresses that crushed the pre-Carboniferous floor, and changing, after equilibrium had been established, into differential subsidence continued into post-Carboniferous times, when the margins referred to were denuded, and even later.

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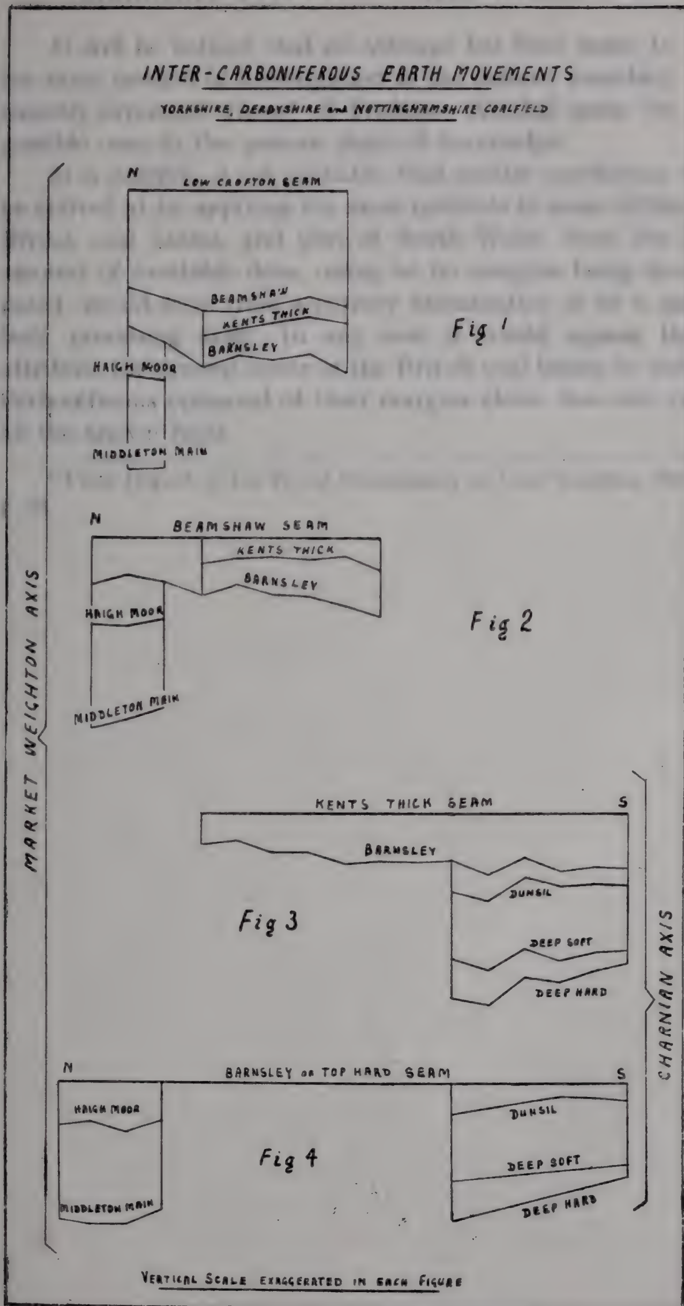
* Geology of Uinta Mountains, p. 201.



Proc. Yorks. Geol. Soc., Vol. XV., Plate LI.

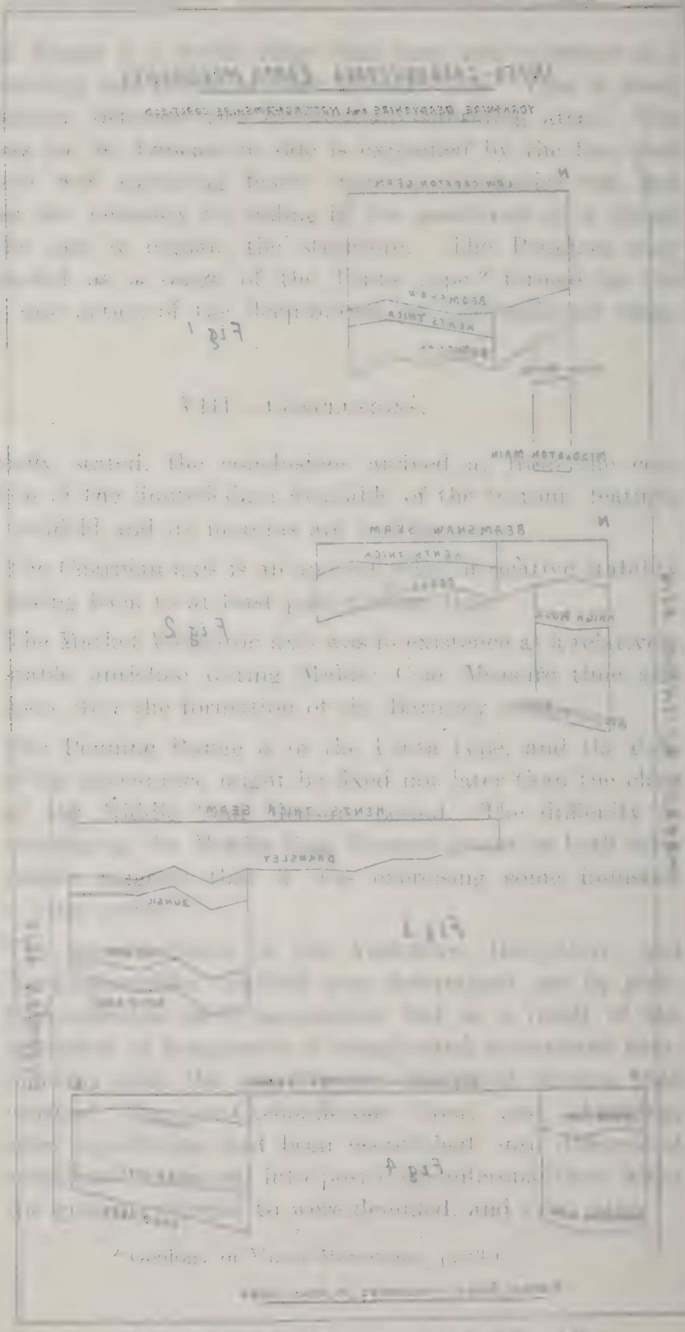


Fig 1
Fig 2
Fig 3
Fig 4

It will be noticed that no attempt has been made to apply the same method of investigation to the eastern boundary. The recently-expressed views* of Professor Kendall seem the only possible ones in the present state of knowledge.

It is possible, if not probable, that similar conclusions would be arrived at by applying the same methods to some of the other British coal basins, and that of South Wales, from the larger amount of available data, owing to its margins being more exposed, would seem from a cursory examination to be a particularly promising area. In any case it would appear that to attribute the present limits of the British coal basins to the post-Carboniferous upheaval of their margins alone, does not explain all the known facts.

* Final Report of the Royal Commission on Coal Supplies, Part IX., p. 31.

FISH FAUNA OF THE LOWER CARBONIFEROUS ROCKS OF YORKSHIRE.

BY EDGAR D. WELLBURN, L.R.C.P., F.G.S., ETC.

Introduction.

In the above group of rocks I include the so-called Yoredale Rocks of the late Prof. Phillips, there being ample palæontological evidence to show that the invertebrate fauna* of these upper beds are almost, if not quite, identical to those of the lower beds. Again, when we compare the list of fish remains given in this paper (all of which are from the upper beds) with a list of those found in the Carboniferous Limestones of Derbyshire, the similarity of the fish fauna of the two is most marked. In Yorkshire the fish remains are found in the uppermost beds of the limestones, the most prolific beds as regards yield being the Main Chert or Red Beds at Harmby Quarry, near Leyburn Railway Station. Others have rarely occurred in the Crow Limestones above, and the Underset limestones below, both in the Leyburn area. Other specimens have been rarely found in upper limestone beds at Richmond, Settle, and Pateley Bridge.

Family Cladodontidæ.

Genus Cladodus Agassiz, Pois Foss., vol. iii., p. 196.

C. mirabilis Agassiz, ibid.

Syn.: *C. mucronatus* J. W. Davis, Quart. Jour. Geol. Soc., vol. xl., p. 619.

Detached Teeth : York and Brit. Mus. (Nat. Hist.), Author's col.

Form and Loc.: Carbonif. limestones, Wensleydale and Richmond.

C. striatus Agassiz, ibid., p. 197.

Syn.: *C. elongatus* Davis, l.c., p. 374.

Syn.: *C. Hornei* Davis, l.c., p. 619.,

Teeth : York and Brit. Mus., Author's col.

Form and Loc.: Carbonif. limestones, Wensleydale and Richmond.

* Dr. Wheelton Hind, F.G.S. Trans.. Edin. Geol. Soc., Vol. vii., p. 342.

GENUS DICRENODUS Romanowsky, 1853, Bull. Soc. Imp. Nat., Moscow, pt. i., p. 408, 1853.

D. dentatus (M'Coy), A. S. Woodward, Cat. Foss. Fish, B.M., pt. i., p. 28.

Teeth : Brit. Mus.

Form and Loc : Carbonif. limestones, Wensleydale and Pateley Bridge.

FAMILY PETALODONTIDÆ.

GENUS JANASSA G. von Münster, Beitr. Petrefakt, pt. i., p. 67.

J. clavata (M'Coy), A. S. Woodward, l.c., p. 37.

Detached teeth : Brit. Mus.

Form and Loc.: Carbonif. limestones, Richmond.

GENUS PETALODUS R. Owen, Odontograph, p. 61 (1841).

P. acuminatus Agassiz, Pois Foss., vol. iii., pp. 174, 384.

Syn.: *P. inæquilateralis* Davis, Trans. Roy. Dub. Soc., vol. i., p. 497 (1883).

Detached Teeth : York and Brit. Mus., Author's col.

Form and Loc.: Carbonif. limestones, Wensleydale, Richmond, and Settle.

P. hastingsiæ (M'Coy), Brit. Pal. Foss., p. 635 (1855).

Teeth : York and Brit. Mus.

Form and Loc.: Carbonif. limestones, Wensleydale and Richmond.

P. flabellula A. S. Woodward, l.c., 1889, p. 45.

Teeth : York Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

P. lamelliformis ? Davis, Quart. Jour. Geol. Soc., vol. xl., p. 625.

Syn.: *Chromatodus lamelliformis* Davis, l.c., p. 625.

Teeth : York Mus., Author's col.

Form and Loc.: Carbonif. limestones, Wensleydale.

Note.—Glyphanodus tenuis Davis. The teeth on which the late J. W. Davis founded this genus and species appear to be worn teeth of some species of *Petalodus*.

GENUS PETALORHYNCUS Newberry and Worthen (ex Agassiz MS.), Pal. Illinois, vol. ii., p. 32, 1866.

P. psittacinus (M'Coy), Morris and Roberts, Quart. Jour. Geol. Soc., vol. xviii., p. 101 (name only), Davis, Rep. Brit. Assoc., p. 645.

Tooth : York Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

P. acutus ? Davis, Trans. Roy. Dublin Soc., vol. i., p. 809, 1883.

Syn.: *Chromatodus acuta* Davis, l.c., p. 809.

Tooth : York Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

GENUS CTENOPTYCHIUS Agassiz, Pois Foss., vol. iii., p. 99.

Syn.: *Petalodopsis* Davis, l.c., p. 498.

C. lobatus (Etheridge), A. S. Woodward, l.c., p. 51.

Syn.: *Ctenopetalodus crenatus* Davis, l.c., p. 513.

Teeth : York and Brit. Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

C. tripartitus (Davis), A. S. Woodward, l.c., p. 54.

Syn.: *Petalodopsis tripartitus* Davis, l.c., p. 499.

Teeth : York Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

GENUS POLYRHIZODUS M'Coy, Ann. Mag. Nat. Hist., vol. ii., p. 125, 1848.

P. colei Davis, l.c., p. 502.

Teeth : York and Brit. Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

FAMILY PRISTODONTIDÆ.

GENUS PRISTODUS Davis (ex Agassiz MS.), l.c., p. 519.

P. falcatus Davis, l.c., p. 519.

Teeth : York and Brit. Mus.

Form and Loc.: Carbonif. limestones, Wensleydale and Richmond.

P. concinnus (Davis), R. H. Traquair, Geol. Mag., vol. v., p. 102, 1888.

Syn.: *Pristicladodus concinnus* Davis, l.c., p. 585.

Teeth : Brit. Mus. and Author's col.

Form and Loc.: Carbonif. limestones, Richmond.

P. benniei (R. Etheridge, jun.), Traquair, l.c., p. 101.

Syn.: *Petalorynchus* (?) *benniei* Etheridge, jun., Geol. Mag., vol. ii., p. 243, 1875.

Tooth : Brit. Mus.

Form and Loc.: Carbonif. limestones, Richmond.

FAMILY PSAMODONTIDÆ.

GENUS COPODUS J. W. Davis (ex Agassiz MS.), Trans. Roy. Dub. Soc., vol. i., p. 464.

Syn.: *Labodus* Davis, l.c., p. 468.

C. prototypus (Davis). A. S. Woodward, l.c., p. 97.

Tooth : York Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

C. cornuatus J. Morris and J. E. Roberts (ex Agassiz MS.), Quart. Jour. Geol. Soc., vol. xviii., p. 100.

Teeth : York and Brit. Mus.

Form and Loc.: Carbonif. limestones, Wensleydale and Richmond.

GENUS PSAMODUS Agassiz Pois Foss., vol. iii. (1838), p. 110.

P. rugosus Agassiz, l.c., p. 111.

Teeth : York Mus., Author's col.

Form and Loc.: Carbonif. limestones, Wensleydale.

P. expansus (Davis), A. S. Woodward, l.c., p. 105.

Syn.: *Astrabodus expansus* Davis, Quart. Jour. Geol. Soc., vol. xl., p. 629 (1884).

Teeth : York Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

FAMILY COCHLIODONTIDÆ.

GENUS HELODUS Agassiz, l.c., p. 104.

H. reticulatus ? Davis, Trans. Roy. Dub. Soc., vol. i., p. 407.

Syn.: *Lophodus reticulatus* Davis, l.c., p. 407.

H. angularis Davis, Quart. Jour. Geol. Soc., vol. xl., p. 628.

Syn.. *Lophodus angularis* Davis, l.c., p. 628.

H. conicus Davis, l.c., p. 627.

Syn.: *Lophodus conicus* Davis, l.c., p. 627.

H. levis Davis, l.c., p. 409.

Syn.: *Lophodus levis* Davis, l.c., p. 409.

H. bifurcatus Davis, l.c., p. 408.

Syn.: *Lophodus bifurcatus* Davis, l.c., p. 408.

H. gibberulus (Agassiz) Davis, l.c., p. 405.

Syn.: *Lophodus gibberulus* Davis, l.c., p. 405.

Note.—All the above " Helodont " teeth are in all likelihood detached anterior teeth of " Cochliodonts," and many probably belong to one and the same fish.

Dr. R. H. Traquair, F.R.S., has figured and described a specimen of *Psephodus magnus* Agassiz, which shows the teeth and cartilages of the jaws. Amongst the teeth shown are some typical of *Helodus* (*Lophodus*) *lævissimus*, *H. rudis* M'Coy, *H. planus*, and *H.* (*Lophodus*) *didymus*.

All the above Helodont teeth are in the York Museum and Author's col.

GENUS VENUSTODUS St. John and Worthen, Pal. Illinois, vol. vi., p. 344, 1875.

V. serratulus (Davis), A. S. Woodward, l.c., p. 225.

Syn.: *Lophodus serratulus* Davis, l.c., p. 408.

Teeth : York Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

GENUS PLEUROPLAX A. S. Woodward, l.c., p. 173.

P. woodi Davis, l.c., p. 458.

Dental Plates : York and Brit. Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

GENUS PSEPHODUS Agassiz (Morris and Roberts), l.c., p. 101.

P. magnus (M'Coy), Brit. Pal. Foss., p. 622.

Dental Plate : York Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

GENUS SANDALODUS Newberry and Worthen, Pal. Illinois, vol. ii., 1866, p. 102.

S. minor Davis, Quart. Jour. Geol. Soc., vol. xl., p. 626.

Lower Dental Plates : York and Brit. Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

GENUS PŒCILODUS M'Coy (emend. A. S. Woodward), Brit. Pal. Foss., 1855, p. 638.

P. Jonesii (M'Coy).

Syn.: *P. corrugatus* Davis, l.c., p. 625.

Dental Plates : York and Brit. Mus.

Form and Loc.: Carbonif. limestones, Wensleydale and Richmond.

GENUS COCHLIODUS Agassiz, Pois. Foss., vol. iii., 1838, p. 113.

C. contortus Agassiz.

Dental Plates : York and Brit. Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

GENUS DELTOPTYCHIUS Agassiz (Morris and Roberts, ex Agassiz MS.), Quart. Journ. Geol. Soc., vol. xviii., 1862, p. 100 (name only).

D. acutus (M'Coy) Morris and Roberts, l.c. (name only).

Syn.: *D. plicatus* Davis, l.c., p. 628.

Small Dental Plates : York and Brit. Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

GENUS DIPLACODUS Davis, l.c., p. 632.

D. bulboides Davis, l.c., p. 633.

Dental Plate : York and Brit. Mus., Author's col.

Form and Loc.: Carbonif. limestones, Wensleydale.

GENUS CYRTONODUS Davis, l.c., 631.

C. hornei A. S. Woodward, Cat. Foss. Fishes, Brit. Mus., pt. i., p. 631.

Teeth : Brit. Mus.

Form and Loc.: Carbonif. limestones, Wensleydale and Richmond.

C. gibbosus Davis, l.c., p. 631.

Teeth : York. Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

FAMILY CESTRACIONTIDÆ.

GENUS ORODUS Agassiz, Pois. Foss., vol. iii., 1838, p. 96.

O. moniliformis Davis.

Syn.: *O. ornatus* Davis.

Teeth : Brit. Mus.

Form and Loc.: Carbonif. limestones, Wensleydale and Richmond.

GENUS DICLITODUS Davis, Trans. Roy. Dublin Soc., vol. i., 1883, p. 410.

D. scitulus Davis, Quart. Jour. Geol. Soc., vol. xl., p. 623.

Imperfect Teeth : York and Brit. Mus.

Form and Loc.: Carbonif. limestones, Wensleydale and Richmond.

ICHTHYODORULITES.

GENUS ERISMACANTHUS M'Coy, Ann. Mag. Nat. Hist., vol. ii., p. 118, 1848.

E. Jonesi M'Coy, l.c., p. 119.

Syn.: *Cladacanthus paradoxus* Davis, l.c., p. 617.

Spines (olim. Capt. Jones' coll.).

Form and Loc.: Carbonif. limestones, Wensleydale.

GENUS PHYSONEMUS M'Coy, l.c., p. 117.

P. hamatus Agassiz, Pois. Foss., vol. iii., p. 9.

Spines : Brit. and Bristol Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

GENUS COMPHACANTHUS ? Davis, ibid., p. 618.*

C. acutus ? Davis, l.c., p. 618.

Spine : York Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

INCERTÆ SEDIS.

GENUS ECHINODUS Davis, ibid., p. 631.

E. paradoxus Davis, l.c., p. 631.

Dermal Fossil : York Mus.

Form and Loc.: Carbonif. limestones, Wensleydale.

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* This genus and sp. probably founded on an abraded spine of another species.

Family Osteolepidæ.

Genus Megalichthys Agassiz, Pois. Foss., vol. iii., pp. 89, 154.

M. Hibberti Agassiz, l.c., p. 89.

Jaw, Teeth, and Scales : York Mus. and Mr. Horne's col. (Laburn).

Form and Loc.: Carbonif. limestones, Wensleydale.

Family Palæoniscidæ.

Genus Elonichthys Giebel, Faun. der Vorwelt Fische, p. 249, 1848.

E. Aitkeni Traquair, Geol. Mag. (3), vol. iii., p. 440.

Scale : Author's col.

Form and Loc.: Carbonif. limestones (Crow), Laburn.

Family Platysonidæ.

Genus Cheirodus M'Coy, Ann. Mag. Nat. Hist., vol. ii., p. 130, 1848.

Syn.: *Hemicladodus* Davis, Quart. Jour. Geol. Soc., vol. xl., p. 620

Cheirodus sp. ?

Syn.: *H. unicuspidatus* Davis, l.c., p. 620.

Pterygoid or Splenial Bones : York Mus.

Form and Loc.: Carbonif. limestones, Wensleydale and Richmond.

THE EVOLUTION OF THE DON RIVER-SYSTEM.

BY W. LOWER CARTER, M.A., F.G.S.

Whilst making a study of river development in Yorkshire a few years ago my attention was attracted to the Don, whose peculiarly erratic course evidently had an interesting history. My surprise was great when no reference to this problem could be found in the geological literature to which I had access. The present paper is an attempt to explain this interesting physical history.

I.—The Don River-System.

The River Don, between its source in the moorlands of the Pennine Chain and its outflow into the Ouse at Goole, has a roughly semi-circular course (Pl. LIII.). Rising in the Middle Grits of the Millstone Grit Series, at an elevation of 1,500 feet above O.D., it flows eastwards to Dunford Bridge (1,000 feet), where it is reinforced by powerful feeders north and south. It then flows eastwards over the Rough Rock, across the strike of the beds and the main faults, and enters the Lower Coal Measures at Hazlehead. At Thurlstone it cuts a gorge through the Grenoside Rock, and then traverses the overlying Penistone sandstones and shales. At Penistone the Don receives the waters of Scout Dike, which, from its source in the moorlands, runs direct east as a dip river (Broadstone Dike), to Ingbirchworth, and then takes a sudden bend to the south-east along the strike of the Penistone sandstones. At Penistone the Don ceases to be a dip river and, changing its direction, runs to the south-east along the strike of the Penistone sandstones in a V-shaped valley, the eastward bank of which rises at Hoyland Swaine to 910 feet, and at Thurgoland to 810 feet, but between these two is a col (730 feet) but little above the contour of the river bed at Penistone (700 feet). The Don quickly deepens its channel to 600 feet at Thurgoland and to 500 feet at Wortley. Between Thurgoland and Wortley the character of the Don Valley suddenly changes from a comparatively broad and smooth-sloped vale to a precipitous gorge, through which the river flows in bold bends, crossing and re-crossing the bedding, and taking to the

Photographed by Godfrey Bingley, Headingley.

THE RIVER DON, NEAR WARMSWORTH (CONISBROUGH GORGE).

The great quarries in the Lower Magnesian Limestone are shown on the right.

Proc. Yorks. Geol. Soc., Vol. XV., Plate LII.

strike for short stretches between. That a river should leave a straight course and form wide bends, not as it leaves but as it enters a hilly region, appears a remarkable fact, and one needing explanation. At Deepcar (440 feet), where it receives on its right bank the Little Don, the river resumes its straight course, and flows almost south, cutting through the great grits of the Grenoside, Greenmoor, and Wharncliffe Rocks of the Lower Coal Measures, with their imposing escarpments. After being reinforced by Ewden Beck on the right bank, it enters a V-shaped valley again at Worrall, receives the combined waters of the Loxley and the Rivelin on its right bank, and, flowing thence south-eastwards to Sheffield (150 feet), enters the Middle Coal Measures (Fig. 3). At Sheffield the Don, making a rectangular bend to the north-east, falls into what I regard as the valley of the Sheaf. The River Sheaf rises on Totley Moor (1,100 feet), flows N.N.E. over the Lower and Middle Coal Measures to Sheffield, where it joins the Don, and thence passes in a broad alluvial valley to Rotherham (84 feet), where the Rother enters it on its right bank. At Denaby it receives the Dearne on its left bank (45 feet), and passes through a picturesque gorge in the Magnesian Limestone at Conisbrough (Pl. LII.) into the Triassic plain (40 feet) at Doncaster. Thence it continues its north-easterly direction to Thorne, where its channel has received much alteration from artificial diversion. The Old Don, the course of which can be traced north of Hatfield Chase and by Crowle to Adlingfleet on the Trent, was probably the pre-historic bed of the stream, which appears to have been artificially diverted at various times to the Trent at Keadby, to the Aire at Snaith, and finally by the Dutch River to the Ouse at Goole.

II.—River Diversion.

The two principles of Physical Geology which are invoked to explain the peculiarities of the course of the Don and its tributary streams are:—

(1) River capture; (2) Glacial diversion.

Both these appear to have influenced the course of the Don, but the former has been by far the more important agent in producing the erratic course of that river. As river capture has not previously been treated of in a paper in the Proceedings of the Yorkshire Geological Society, it may not be out of place to give a brief *résumé* of the theory of its action.

The principle of river struggle with the survival of the fittest was first applied by Professor Jukes to explain certain anomalies of the Blackwater and other rivers of Southern Ireland.* The American geologists have expanded his suggestions into a scientific scheme for dealing with their extensive river problems, and have by this principle solved many of the complicated questions of American physical geography. Professor W. M. Davis,† Mr. Jukes-Browne,‡ Professor P. F. Kendall,‖ and Mr. Cowper Reed§ have also applied the same method to the explanation of the erratic courses of certain English rivers. In considering the conditions of the struggle of rivers for the possession of a watershed it is evident that some will be equipped more advantageously for the conflict than their neighbours. The three chief conditions of success are:—

1. Slope; the greater the fall of a river the faster will it flow and the greater will be its cutting power. Hence the steeper the slope the more rapidly will the stream intrench itself, and thus obtain a commanding place in the watershed.

2. Volume; the larger the volume of a river the greater will be its excavating power.

3. Softness of bed; the material of the rocks over which a river flows will be a considerable factor in deciding the rate of denudation, and therefore the river that flows over the softer strata will have a considerable advantage in the struggle over neighbours flowing over harder rocks.

These principles make it evident that a river that was advantaged in two or three of these respects would be able to cut down its channel more rapidly than a rival less advantageously situated, and in turn to cut back further into the watershed, and thus obtain a larger area of the rainfall-catchment. This advantage would be shared by each of the predominant

* Q.J.G.S., xviii., 1862.

† Geographical Journal, v., 1895, p. 127.

‡ Q.J.G.S., 1883, p. 596.

‖ Chairman's Address, Yorks. Geol. Soc. Whitby Meeting, Aug. 1st, 1896.

§ The Geological History of the Rivers of East Yorkshire. 1901.

river's feeders, for the fall of each of them would be increased by every deepening of the main channel, and so they would have increased ability to cut back into the secondary watersheds, and thus in all directions the power of the predominant river would be increased and its permanent success be assured in the struggle for pre-eminence. A simple diagram will make this plain (Fig. 1). Consider RS as the main watershed, down the dip-slope of which flow three rivers, dividing it into valleys separated by the secondary watersheds WX and YZ. Suppose for simplicity that the central stream B has all three advantages, and so holds a commanding position with regard to its lateral rivals. It will thus intrench itself more deeply than its neighbours, and be able to cut back more rapidly into the main watershed. The deepening of the principal channel B will give the feeders F and G, which begin to work along the outcrops of the two prominent grit beds OO' and PP', a steeper slope, which will increase their velocity, and they in their turn will be more effective in cutting back into the secondary watersheds WX and YZ. In time these advantages will enable them to invade the water-catchment areas of their competitors, and to filch from them some of their tributaries (E, H). Every gain of this sort will increase the volume of the principal stream, and thus its cutting power, and enable it to make fresh depredations on its neighbour's territory. Ultimately this may go on until the river B is able to cut back so far into A's drainage area that it can capture its head stream D. The original streams, A, B, C, flowing down the slope of the main watershed, are called dip or *consequent* streams; the lateral feeders developed along the strike of the beds are termed *subsequent* streams. After capture of the head waters, the residuary streams below the angle of

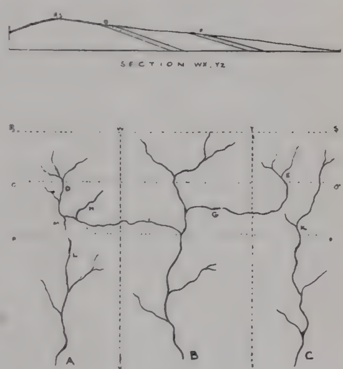

Fig. 1.

DIAGRAM OF RIVER CAPTURE.

capture (L, K) are called *beheaded remnants*, and any stream (M) flowing back along the old bed from the escarpment into the capturing river is called an *obsequent* stream.

In glacial diversion the normal drainage is obstructed by an advancing ice-front, and a lake is formed, the overflow from which cuts a new channel across the lowest part of the enclosing watershed. This channel, if only occupied for a comparatively short period, may be deserted on the retreat of the ice-barrier, and the stream will then return to its old channel, unless that is obstructed by morainic deposits, when the overflow from the diminished lake will cut a new channel across or at the side of the moraine. If the glacial obstruction persist for a period sufficiently long to allow of the drainage overflow cutting down its channel below the contour of the original stream bed, or below the level of the moraine if the old valley be obstructed, the removal of the ice-barrier will not influence the course of the stream, which will continue to follow the new gorge, and establish itself as the main river-channel.

III.—The Upper Don.

In considering the Upper Don by the help of the foregoing principles of river capture, it is evident that the upper portions of two of the streams (Broadstone Beck and the Don above Penistone) partake of the character of consequents, i.e., they flow eastwards down the slope of the Pennine arch and across the dip of the strata. On the far slope of the opposing low watershed, on each side of the higher land of Hoyland Swaine, streams are found also running eastwards, and giving a strong suggestion of ancient continuity of flow. These latter streams are interpreted by the author as the beheaded remnants of the consequents in question.

The eastern retaining watershed of the Don below Penistone (Pl. LIII.) is evidently a continuation northwards of the plateau of Wharncliffe Chase, a great portion of which is above the 800-foot contour. In this watershed there are outlying patches of land above this contour (800 feet) at Thurgoland and Hoyland Swaine, but the intermediate parts of the ridge have been lowered by denuding agencies to form a col opposite each of the streams

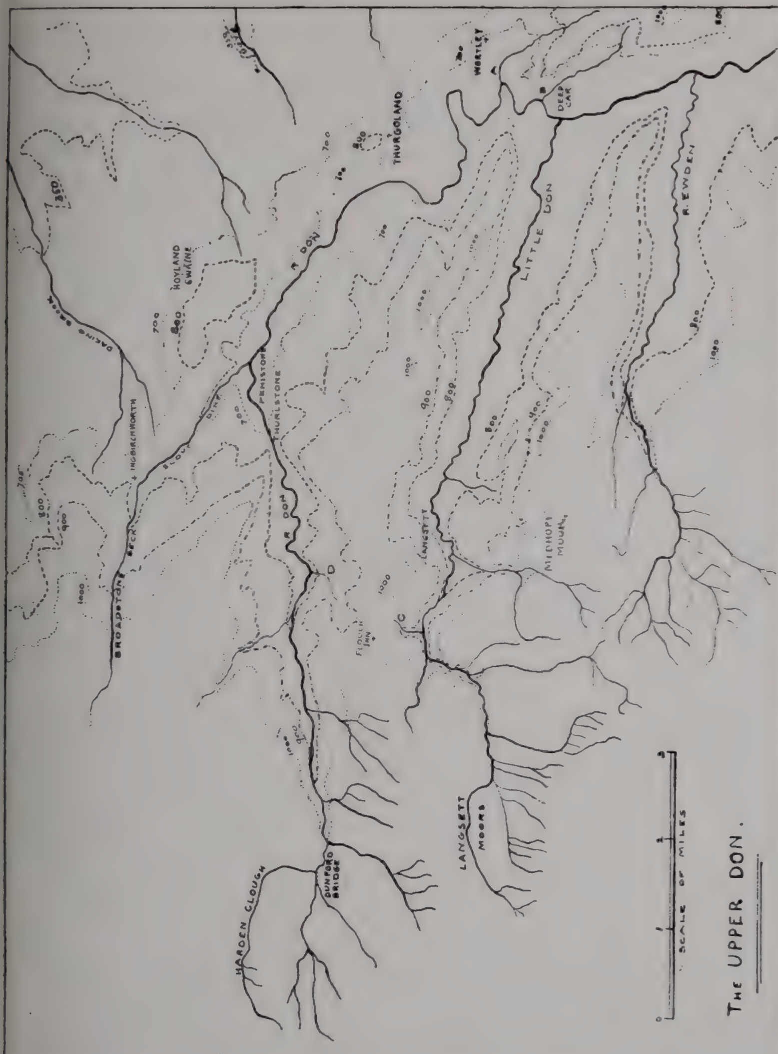

Fig. 2.

MAP OF THE UPPER DON.

in question. Thus Broadstone Beck flows eastwards to Ingbirchworth (Fig. 2), and just on the 750-foot contour bends to the south-east. Directly opposite to it at this bend is a dip of the contour of the opposing watershed to 750 feet, which the stream avoids, cutting its channel southwards, as Scout Dike, through the higher land at Hoyland Swaine. Just over the watershed at Ingbirchworth rise the head waters of Daking Brook, which flows by Cawthorne into the Dearne. Again, the Don at Penistone faces a dip to 730 feet in the eastward ridge, between the 800-foot contours of Hoyland Swaine and Thurgoland, and on the other side of this ridge the Dove takes its rise, continuing the line of the Upper Don eastwards. Turning away, however, from this col southwards, the Don strikes into the elevated plateau of Wortley, which rises in several places to more than 1,000 feet on either bank. It is obvious that in order to cut through a ridge of 1,000 feet water must have flowed at that elevation when this work of denudation commenced. But no reconstruction of the physical geography will permit us to assume a barrier from Wortley to Hoyland Swaine of such a height as to compel the waters of the Don to take this southern course. We must therefore seek for a more satisfactory explanation, and that of river capture is the most feasible. This teaches us that a stream flowing southwards from the Wharncliffe watershed cut its way back through that ridge, tapped the streams of the Don and Broadstone Beck successively at Penistone and Ingbirchworth, and drew their upper waters down by its steep channel through the Wharncliffe gorge to the Sheaf at Sheffield, and left the Dove and Daking Brook as beheaded remnants to flow eastwards from the edge of the new ridge which was produced gradually by the deepening of the new valley of the Don.

Usually after passing in a fairly straight course through a mountain gorge a river on debouching into a plain at once, its velocity being checked, begins to migrate in wide loops, to and fro in the flat land. The opposite to this happens in the case of the Don. It flows south-eastwards in a straight course from Penistone to Thurgoland in a V-shaped valley, but on entering the gorge through the Wharncliffe plateau, it suddenly makes a rectangular bend to the S.W., taking a bold semi-circular curve, then doubles on itself and comes round to Wortley in another great curve, where it receives a beck which flows northwards from Wharncliffe Chase and bends round to enter the Don. After another marked loop the river receives another feeder from the Chase plateau also flowing northwards. These we may call A and B (Fig. 4). At Deepcar the Don receives the Little Don on its right bank. This I regard as a subsequent stream which has worked its way along the junction of the Millstone Grit and the Lower Coal Measures, which here bend round to the west, and, cutting back in the direction of Langsett, has captured the head-waters of the Penistone and Dunford branch of the Don. This view is supported by the sudden change in the direction of the feeders of the Little Don at Langsett (Fig .2) ; and the existence of a flat col at the Flouch Inn, about a mile N.W. of Langsett, with a small stream flowing from each side of it, is also suggestive. These feeders, C and D, would on my theory be an obsequent stream (C) and a beheaded remnant (D). Returning to the Wharncliffe gorge (Fig. 4) we notice that from Deepcar southwards the Don cuts a straight channel through the Wharncliffe plateau, receiving two large feeders, the Ewden and the Loxley on its right bank, and flows in a S.S.E. direction to Sheffield. On the left bank at Oughtibridge it receives a couple of little streams which descend from the Chase through Wharncliffe Wood, and may be indicated by C and D (Fig. 4). That Wharncliffe Chase was the original watershed between Wortley and Oughtibridge seems to be indicated by the direction of these feeders. The streams C, D flow in the normal way of feeders of the Don, but A and B are quite abnormal, flowing north from the Chase as if they ran into a river draining northwards, and then bending round in a most unnatural manner to flow into the Don, which there runs parallel to their upper reaches, but in the opposite direction.

This northward flow of A and B I believe to have been the original direction of their course when there was a stream draining Wharncliffe Chase northwards, and that the bends they make to join the Don are the results of river capture, by which this flow has been reversed. Fig. 4 gives my suggestions for explaining these anomalies, and also makes clear the existence of two deserted cols at Wortley (560 feet) and Thurgoland (675 feet). These cols lie in the direction of the original course of the stream A, and are, I believe, relics of its channel. If this be so the relative

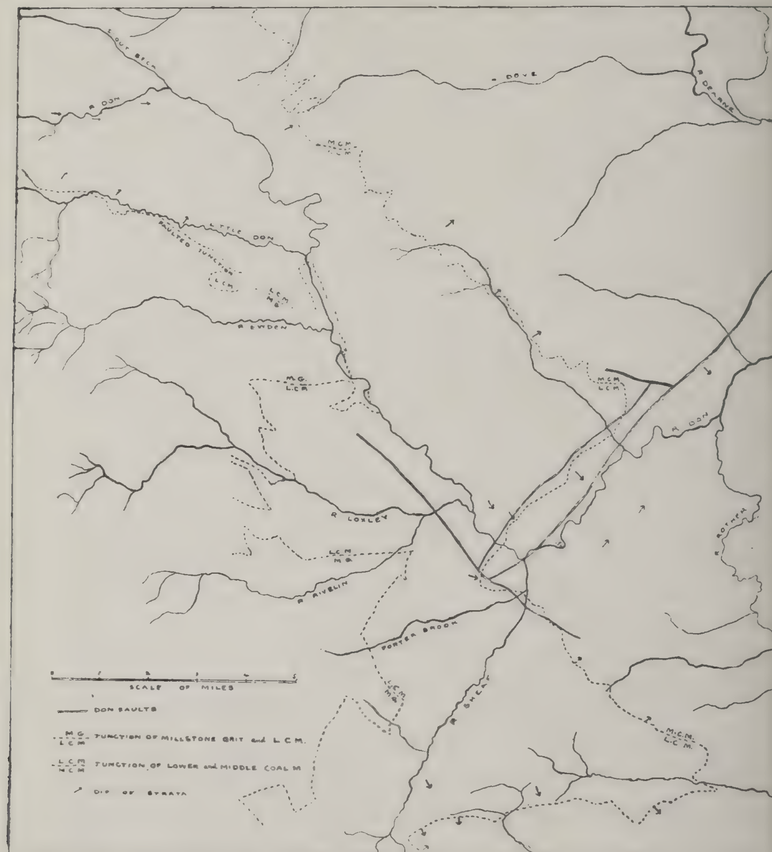

Fig. 3.

MAP SHOWING THE OUTLINE OF THE GEOLOGICAL STRUCTURE OF THE DON VALLEY.

height of the cols shows that the stream A must have been tapped at Thurgoland first, and afterwards that a little torrent flowing into the Don at Wortley (E, Fig. 4, III.) must have cut back its channel and tapped the stream higher up at Wortley. That this was a much later effect is shown by the fact that A had been able to cut down its bed at least 115 feet in the interval.

IV.—The Geological History of the Capture of the Don.

From the close of the Carboniferous Period, with the exception of the Trias uplift, one may say that there was a general tendency for the Pennine Chain to slowly subside, with the gradual encroachment of the Permian, Jurassic, and Cretaceous rocks, overlapping each other against this old land area. The probability is that the Pennine range was not submerged beneath the Cretaceous sea until Middle or Upper Cretaceous times,* and that there was never any great thickness of Chalk on the higher parts of the range. Thus when the Tertiary uplift commenced the Pennine arch would reappear surrounded by a wide-stretching plain of oozy chalk, which would easily be disintegrated by sub-aerial denuding agencies, and the underlying Carboniferous land surface would be revealed before the major lines of drainage had had time to establish themselves. The early drainage would consist of endless runlets wandering about on the soft surface of the Chalk, and quickly denuding it. Where, as the uprise continued, an old Carboniferous river channel became revealed, it would at once determine the main line of drainage for that area, and even if it were filled with chalk the unequal denudation of the hard old and the soft new rocks would soon reveal the old features, and the new valley would be compelled to follow the line of the old channel. Where this commenced at the earliest period of Eocene denudation, there would be nothing to prevent the old channel being followed at all subsequent phases of the uplift. This is my explanation of the predominance of the Sheaf as the capturing river of this system. The valley of the Sheaf has many signs of being an ancient geological feature. It follows the line of a marked Carboniferous synclinal, which is traversed by two parallel valley faults (Fig. 3). As there appears to be evidence for the subsequent movement of these lines of fault in Permian times, and it is common for lines of weakness

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* Jukes-Browne, Building of the British Isles, p. 191.

in one period to suffer movements at intervals in subsequent periods,* there seems no valid objection to the supposition that there may have been oscillations along the line of the Don faults as late as Cretaceous times. This suggestion may also help to give plausibility to the supposition that the Sheaf valley was from the beginning easier to erode than the adjacent valleys, owing to the denuding agents having an old valley filled with Chalk to commence upon. This would account for its occupying a commanding position in the struggle for supremacy from a very early period. This supposition may also account for the unusual direction of the Sheaf, which follows the faulted syncline of the Middle Coal Measures and flows north-east instead of east, as is the case with the other consequent streams of this district. (Fig. 3).

A comparison of the level of the Sheaf at Sheffield (150 feet) with that of the Don at Penistone (700 feet), each about the same distance as the other from its source, shows how great must have been the advantage possessed by the southern river over the northern in the struggle for the Wharncliffe watershed. A reason for this may be found in a comparison of the rocks over which the two streams flow. The Penistone Don has to deal with the Millstone Grit and the Grenoside Rock, whereas the Sheaf flows entirely over Lower and Middle Coal Measures, and massive grits are not nearly so predominant in this area as they are northwards.

For instance, the Grenoside Rock, which is recognisable but not a conspicuous bed in the valley of the Sheaf, swells out northwards to 100 feet above Sheffield, and is 75 feet thick at Penistone.† The Wharncliffe Rock also, which is an ordinary sandstone in the Sheffield district, swells out at Wharncliffe into a great wedge of highly siliceous grit 90 feet thick, forming the most prominent rock of the neighbourhood.‡

Coming now to the consideration of the Wharncliffe watershed, I venture to suggest that on going back say to Miocene

* As noted by Professor Kendall in Rep. of Royal Comm. on Coal Supplies; also in the case of the Cleveland anticline in a paper read at the Yorks. Geol. Society's meeting, Thirsk, June 2nd, 1905 (not yet published).

† Geology of the Yorkshire Coalfield, p. 135, &c. ‡ Ibid, p. 117.

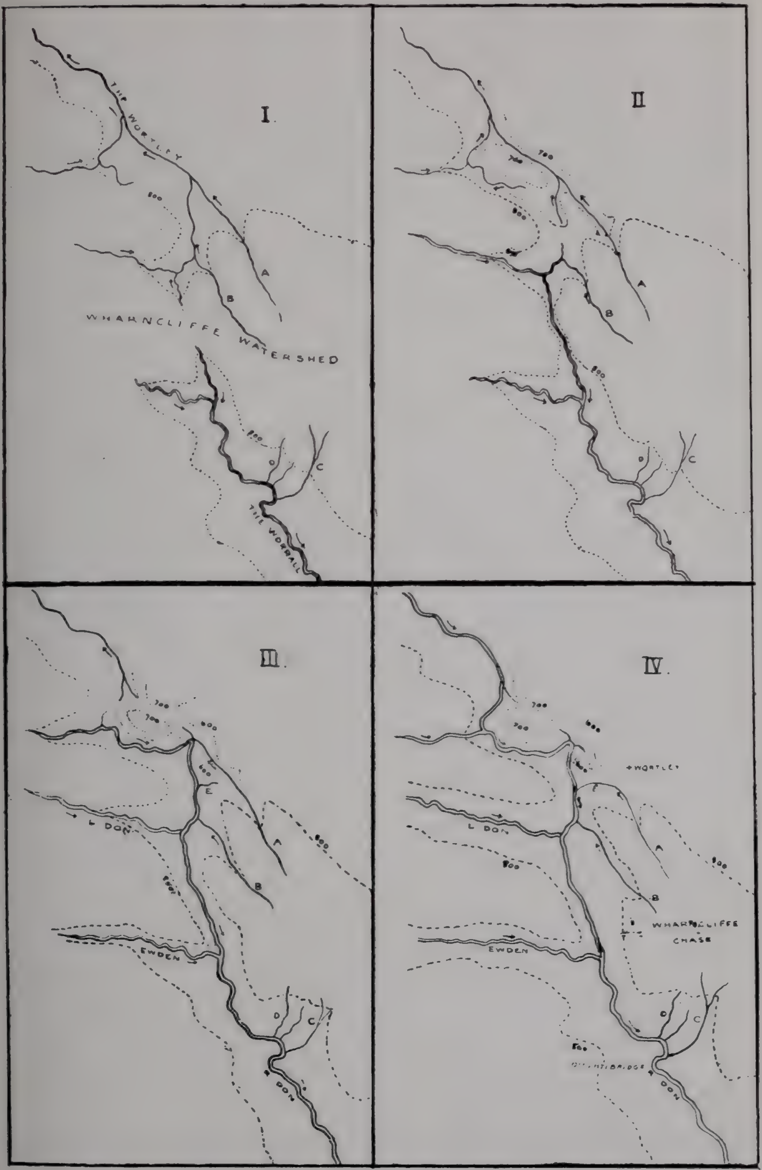

Fig. 4.

DIAGRAM SHOWING THE STEPS SUGGESTED BY WHICH THE CAPTURE OF THE PENISTONE DON BY A FEEDER OF THE SHEAF WAS EFFECTED AND THE CONVOLUTIONS AT WORTLEY WERE PRODUCED.

The Capturing River is represented by the double line, the Captured River by the single line.

times, it would be found that the plateau with its three great grits, the Grenoside, Greenmoor, and Wharncliffe Rocks, would stretch unbroken from Wharncliffe Chase to Langsett, the northern area being drained by the Don, which I suppose then to be reinforced by the head waters of the Little Don (Fig. 5) and a feeder, which we may call " the Wortley " for convenience, draining the northern slope of the Chase. Southwards the whole of the drainage was collected by powerful, wide-stretching streams, the Ewden, the Loxley, and the Rivelin, and collected in the strike river flowing south to Sheffield, which we may term " the Worrall " (Fig. 4). Thus the struggle for the Wharncliffe watershed between the Wortley and the Worrall would be most unequal from its commencement. The Wortley, having only a small fall towards its parent river, and a limited watershed, would be very unfavourably situated for successful attack; whilst the Worrall, reinforced by its powerful feeders, with their great combined area of watershed, and a steep fall towards the Sheaf, would be able to cut its way back into the watershed powerfully and rapidly. It is evident that along each of the lines of advantage for River Capture the Worrall was far superior to the Wortley. At an early stage the Worrall was able to capture the Loxley and the Ewden, if they were original consequents, but they may be simply feeders which worked their way back into the moorlands with power to deepen their valleys rapidly as the principal stream cut down its channel.

As the Worrall cut its way down and back into the Wharncliffe plateau, it would be able to annex successively the feeders of the Wortley, the beginnings of the Little Don at Deepcar (Fig. 4, II.), the stream B to the north on the opposite bank, and then the eastward feeder A from the Chase at Wortley, leaving the col at Thurgoland (675 feet) dry (Fig. 4, III.). The great denuding power of the southern river would enable each of these streams to deepen its bed with increasing rapidity, and would give power to such lateral feeders as E (Fig. 4, III.) to cut through the secondary watershed and tap A at an intermediate point between Wortley and Deepcar, thus leaving the dry col (560 feet) at Wortley (Fig. 4, IV.). The Little Don meanwhile cutting back along the junction of the Millstone Grit and Lower Coal Measures, and unhindered by the Wharncliffe Grit, which thins out rapidly westwards as well as southwards, would soon lengthen its course, and ultimately capture the head waters of the Penistone Don above Langsett, leaving the col at the Flouch Inn (Fig. 2). The main stream would at the same time continue its cutting work backwards along the course of the Wortley until it captured the Don at Penistone, and enabled Scout Dike in its turn to work back and capture Broadstone Beck, leaving the Cawthorne stream and the Dove as beheaded remnants (Fig. 5). This would complete the evolution of the form of the Upper Don, which since then has been occupied with establishing itself more and more deeply in its new channel.

V.—The Dearne.

Turning now to the Dearne, we find north of Ingbirchworth that the Penistone Flags bend round to the north-east and east, and two strike streams flowing along Denby Dale and from Shelley (Pl. LIII.), along the junction of the Lower and Middle Coal Measures, unite to form the Bretton stream. This stream makes a sharp south-easterly bend at Haigh, where it faces the escarpment of Woolley Edge, and, flowing on by Darton, receives the Cawthorne stream. The strike of the Middle Coal Measures at Woolley Edge bends round to the south-east, and the Bretton stream follows the strike, changing from a dip to a strike river. This suggests that the Darton branch of this stream is a subsequent which captured the Bretton stream at an early date, probably before the capture of the Penistone Don, as there is no mark of a channel or dip at the part of Woolley Edge at which one would expect it. The Cawthorne stream, which appears to be the original strike river which captured the Bretton, flows across the Middle Coal Measures in an easterly direction, cutting through the Woolley Edge, Oaks, Lower, Middle, and Upper Chevet Rocks (Fig. 6), and then makes a rectangular bend to the south at Great Houghton, turning away from the escarpment of the Great Houghton Rock, and becoming a strike river, which passes along the edge of the Upper Chevet Rock as far as Darfield, where it bends round again, crosses the Upper Chevet Rock backwards, in a narrow,

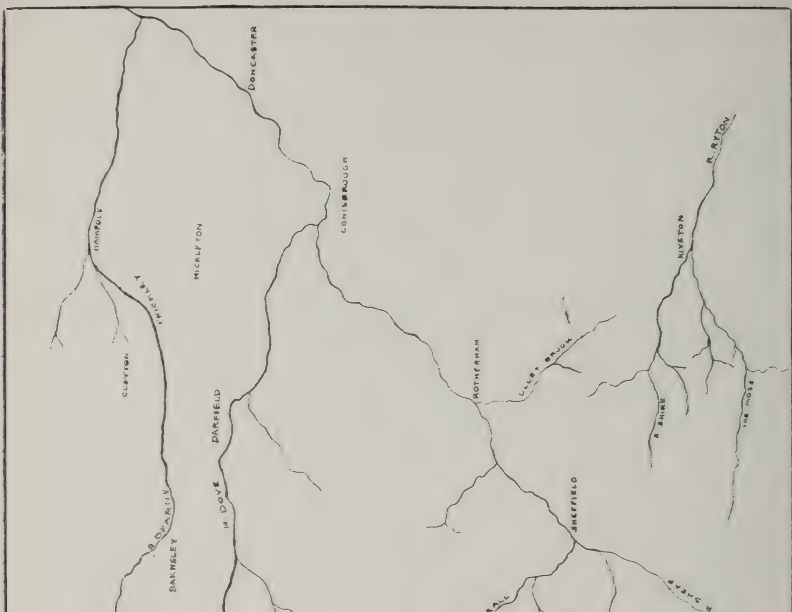

Fig. 5.

MAP SHOWING SUGGESTED FORM OF THE DON RIVER-SYSTEM IN PLIOCENE TIMES.

deep gorge, and falls into the valley of the Dove. A short distance to the east of the Dearne at Darfield is a little beck, Thurnscoe Dike, which takes its rise in the shales between the Great Houghton and the Houghton Common Rocks, flows first as a strike stream, and then, crossing the end of the deserted valley which passes north of Bolton-on-Dearne, swings back parallel to the Darfield Gorge, and crosses the Upper Chevet Rock into the valley of the Dove at Carr Head (Fig. 6).

That these streams should turn away from the wide open country in front of them, and especially from open valleys like that of Little Houghton and Bolton-on-Dearne, without some very powerful compulsion, seems incomprehensible, and in my paper on the glaciation of this area* I have tried to show how the advance of a glacier from the north through Frickley Gorge would effect these curious diversions. I suggest as probable that the Dearne, which is a dip river as far as Little Houghton, crossing the Woolley Edge, Oaks, Lower, Middle, and Upper Chevet Rocks (Fig. 6), in pre-glacial times flowed on along a normal dip course, cutting through the Great Houghton Rock at Thurnscoe and the Houghton Common Rock at Frickley (200 feet). The deserted valley at Frickley between Clayton and the Magnesian Limestone escarpment at Hickleton, has the appearance of an old river valley of considerable antiquity, the centre of which, at the 200-foot contour, is quite streamless, and the sides rise in a mile on either hand, at Clayton and Hickleton, to the 300-foot contour, and then slope upwards to 385 feet and 362 feet respectively above O.D. This gorge opens out northwards into a wide valley, drained by several little dikes which unite in a small stream which flows through the Magnesian Limestone by the old gorge of Hampole (Pl. LIII.). This gorge, which is comparable with that of the Don in importance, appears to require a much more considerable river to explain it than the small stream which it now conveys (Fig. 7). I venture to suggest that the Dearne in pre-glacial times, after flowing through Frickley Gorge, found its way through the Permian escarpment into the Triassic plain by Hampole Gorge (Fig. 5).

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*See p. 427.

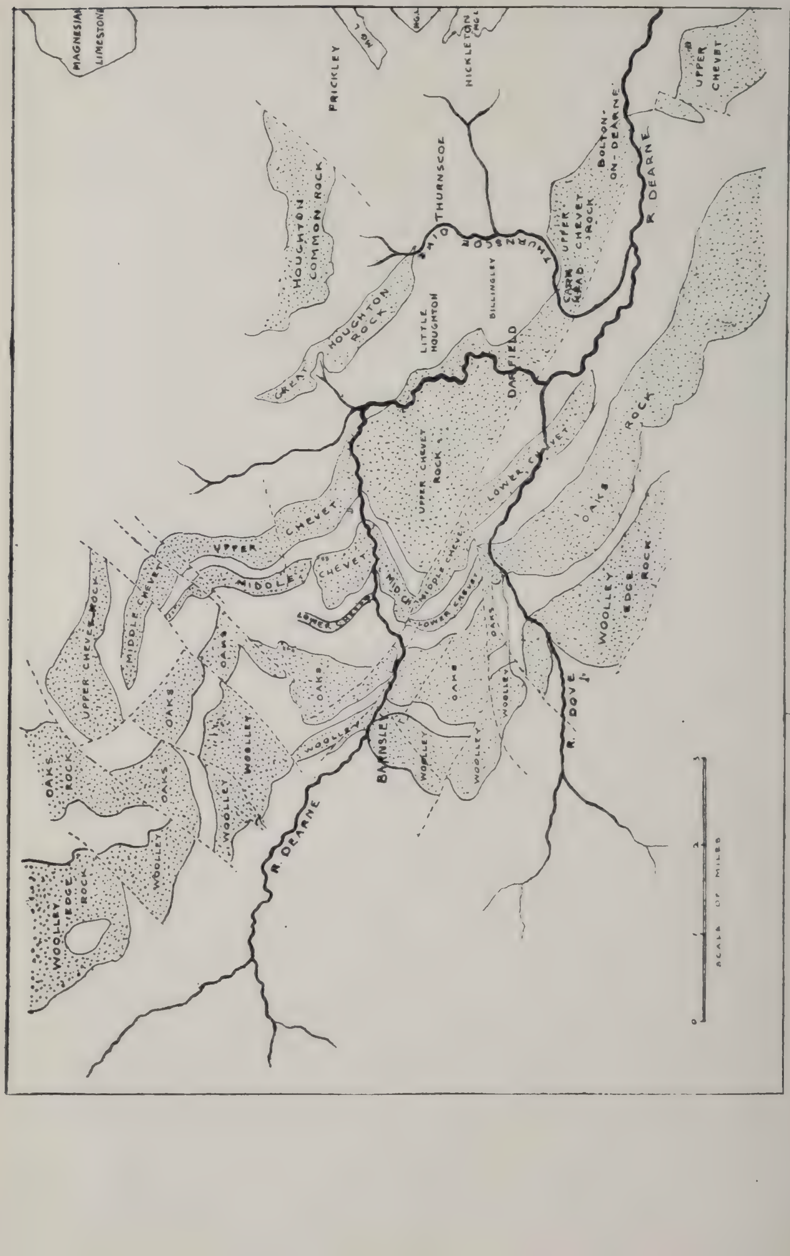


Fig. 6.

MAP SHOWING THE RELATION OF THE DON AND THE DEARNE TO THE CHIEF GRITS OF THE MIDDLE COAL MEASURES.

This supposition demands a considerable extension westwards of the Hickleton escarpment of the Magnesian Limestone in order to provide a satisfactory watershed separating the Dearne from the Dove in pre-glacial times. The way in which the Magnesian Limestone pushes out shallow spurs over the Middle Coal Measures near Hickleton suggests that this was the case (Fig. 6), and the base of the Permian at Hickleton is no less than 340 feet above O.D. Drawing a line westwards from Hickleton to Darfield, the level of the shales and soft sandstones gradually declines to 150 feet above O.D. at Thurnscoe Hall, and when the post-glacial valley of Thurnscoe Dike is crossed, the contour of 175 feet is quickly reached at Billingley. Thus it does not seem impossible that a low watershed of shales and soft sand-

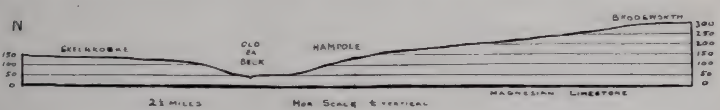


Fig. 7.

SECTION ACROSS THE HAMPOLE GORGE IN THE MAGNESIAN LIMESTONE.

(This Section was made on the same scale and for comparison with the Don and Balby Section, Fig. 4 in "The Glaciation of the Don and Dearne Valleys.)

stones, say up to 250 feet, possibly capped by a thin limestone bed, may have been all that the glacier moving southwards through Frickley valley had to meet. In my paper on the glaciation of this area* I have tried to show how the oncoming of this glacier would account for the gorge of the Dearne at Darfield and for the erratic course of Thurnscoe Dike.

VI.—The Rother.

In considering the Rother one finds a river of considerable complexity, which exhibits some curious features (Fig. 8). The main channel of the modern Rother south of Woodhouse and its direct continuation, the Doe Lea, form a subsequent stream

* See p. 427.

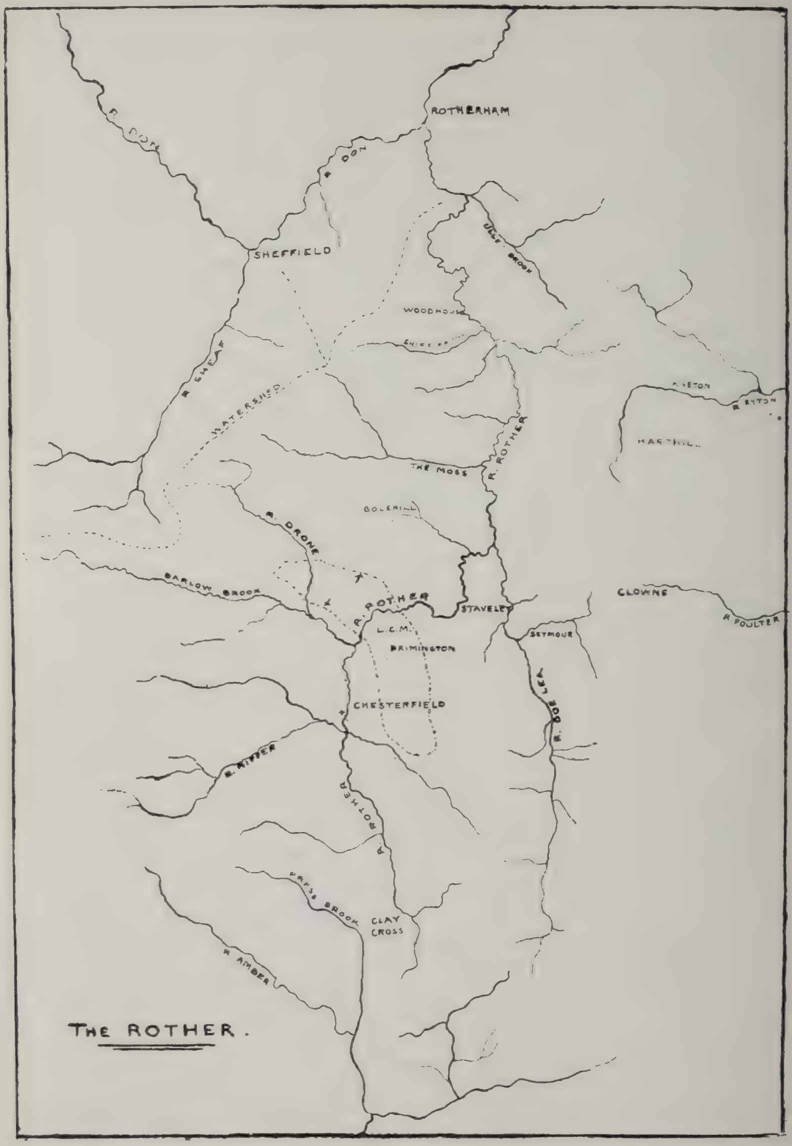


Fig. 8.

MAP OF THE RIVER ROTHER.

running through the Middle Coal Measures, roughly parallel to the Magnesian Limestone escarpment, which it has denuded into a fairly straight ridge. Parallel to the Doe Lea, and separated from it by the Brimington anticlinal of Lower Coal Measures, is another subsequent stream, which has worked its way backwards along the strike of the Middle Coal Measures southwards to Clay Cross.

These streams are united by a dip stream, Barlow Brook, which rises in the Lower Coal Measures of Ransley Moor and Car Top, receives the River Drone, and flows directly east to Staveley. Here it makes a curious double rectangular bend to the north and east, and falls into the Doe Lea near Renishaw. Flowing down from the edge of the Magnesian Limestone escarpment at Clowne, towards Seymour Colliery, is a stream the course of which suggests that it is the obsequent from Barlow Brook, after capture by the subsequent Rother; and at Clowne, though there is no gap in the ridge, the head waters of the Poulter rise almost at the edge of the escarpment, and may represent a beheaded remnant. Following out these suggestions, the easiest way of explaining this curious physical structure appears to be to assume that Barlow Brook is the chief consequent of this district, and that originally it flowed eastwards over the Permian ridge. Also that the Doe Lea and the Chesterfield branch of the Rother are subsequents which have worked back each along the strike of a belt of Middle Coal Measures. When Barlow Brook was captured by the Rother, the Poulter was left as the beheaded remnant.

At Kiveton the Magnesian Limestone is traversed by a gorge (Fig. 8 and Pl. LIII.) commencing at the 300-foot contour at the western end, through which a little stream runs, which rises at Harthill on Middle Coal Measures, makes a rectangular bend as it enters the gorge and flows through it into the Ryton. Directly west of the entrance to the gorge there is a circular patch of higher ground, called Wales, rising to the 400-foot contour, with a dip in the contour on each side of it to 330 feet (Pl. LIV.). From the more northerly of these cols a stream flows back into the Rother, and the canal has diverted a similar small stream from the southward col.

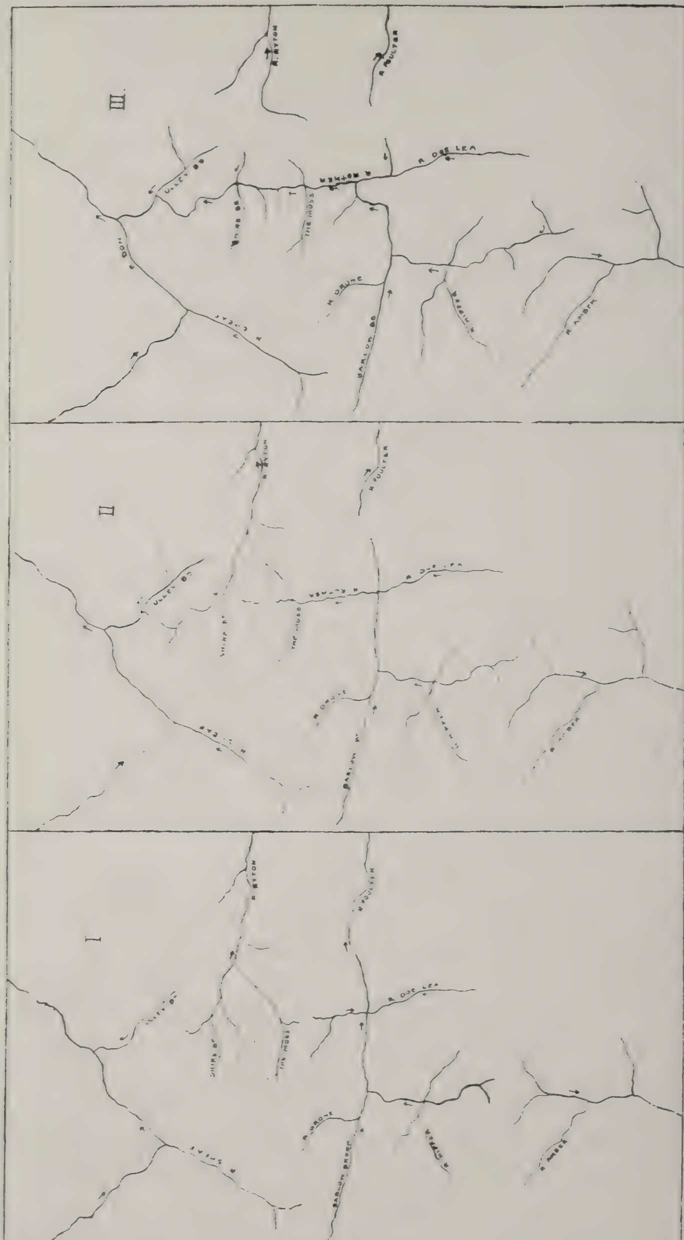


Fig. 9.

DIAGRAMS OF THREE STAGES IN THE EVOLUTION OF THE ROTHER BY RIVER CAPTURE.

On the western bank, almost opposite to these cols, the Rother receives two dip streams, Shire Brook and the Moss. My suggestion is that prior to the erosion of the subsequent valley of the Rother, the Moss and Shire Brook flowed eastwards on each side of Wales (Fig. 9) and united to form the Ryton, but that they were afterwards captured by the subsequent Rother. At Woodhouse the Rother suddenly ceases to be a strike river, and cuts its way across the Treeton Rock to Ulley Beck, which flows in a wide old valley northwards along the strike of the Red Rock of Rotherham to join the Don.

At the extreme southerly end of the Rother also, near Clay Cross, there are some curious features. The lop-sided course of the Amber and Press Brook, and the anomalous direction of one or two of the feeders of the Rother, suggest that the Chesterfield branch of the river has cut back sufficiently far to capture some of the head waters of the Amber, i.e., of the Derwent (Fig. 9, II., III.).

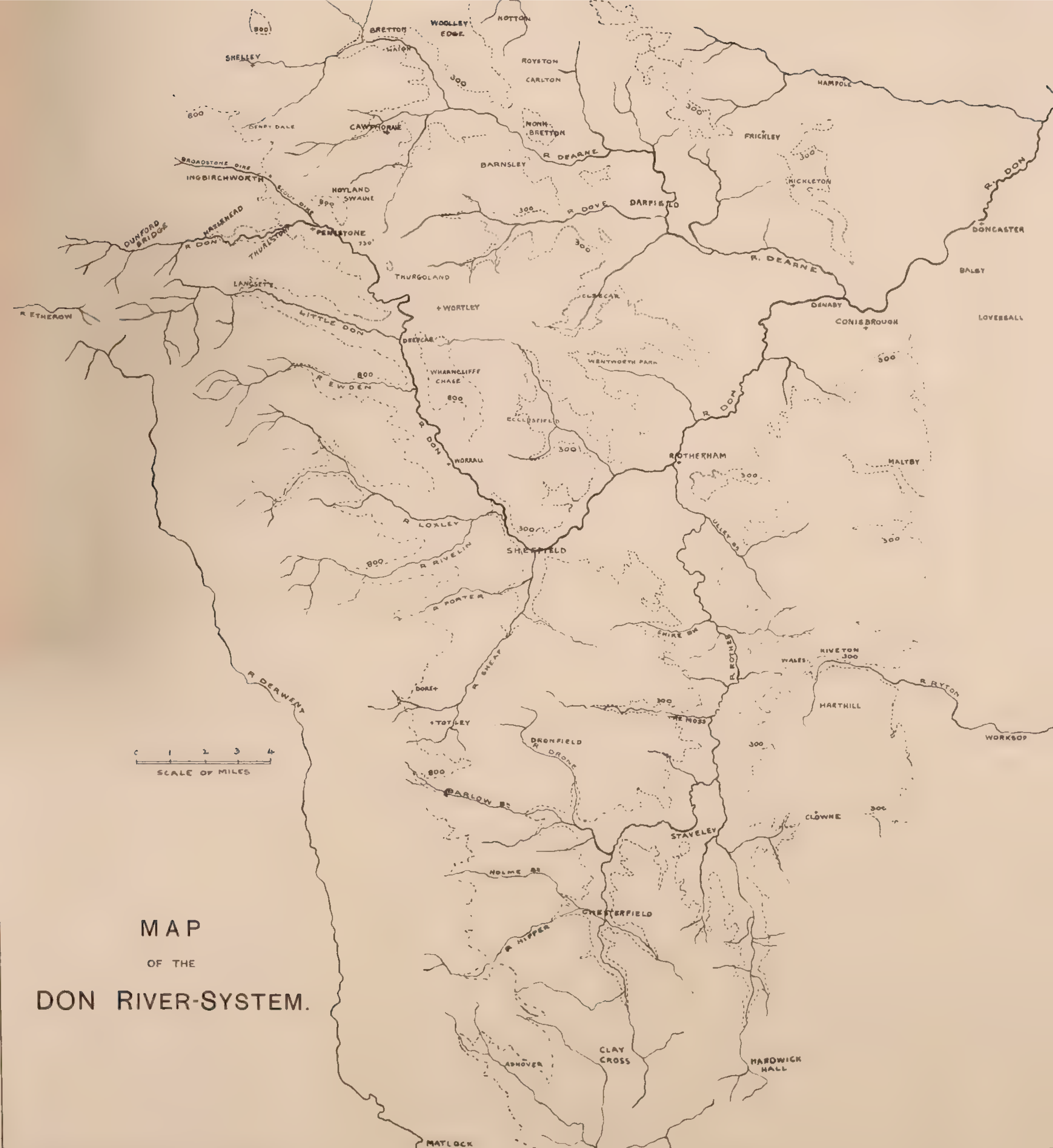
In attempting to frame a consistent explanation of these several difficulties, I venture to suggest that before the Permian escarpment reached its present level there were two rivers draining the slope from the central watershed eastwards, (1) the Ryton, with its twin heads, Shire Brook and the Moss; (2) Barlow Brook, flowing into the Poulter by Clowne. From Shire Brook and the Moss subsequent streams began to eat north and south along the escarpment, and from Barlow Brook there were also working north and south subsequent streams, the Doe Lea and the infant Rother also along the line of the Permian escarpment. While higher up in the course of the Barlow the Chesterfield stream was another subsequent working along the belt of Middle Coal Measures west of the Lower Coal Measure anticlinal of Brimington (Fig. 8). On the north Ulley Brook flowed northwards to the Don in a strike valley, and one of its branches worked its way gradually back into the watershed at Treeton.

The second stage in this evolution would be arrived at by the cutting back of the subsequent streams. South of Barlow Brook the Doe Lea and the Chesterfield stream lengthened their courses. Northwards the Drone bit deeper into the central tableland, and the Rother wore its way along the line of the Permian escarpment until it tapped the feeder of the Moss on the one hand and Barlow Brook on the other (Fig. 9).

Thus the whole of the drainage of the river south of Staveley was drawn northwards along the strike of the Magnesian Limestone, and discharged into the Ryton by Kiveton Gorge, the Poulter being left at Clowne as a beheaded remnant. A consequent feeder of Shire Brook at the same time was working its way back into the Treeton watershed to meet the feeder of Ulley Brook. In the course of time a third stage (Fig. 9, III.) was reached, when the combined efforts of Ulley Brook and the Rother cut through the Treeton watershed, and then the low level at which the Don ran, as compared with the Ryton, enabled it to capture the Rother and all its tributaries, leaving the Kiveton Gorge as a deserted channel and the Ryton as a beheaded remnant.

The curious elbow at Staveley (Fig. 8) may be a later diversion due to the vigorous little stream which rises at Bolehill and Middle Handley, developing a little consequent along the strike of the Middle Coal Measures which tapped the Rother at Staveley, and brought it to Renishaw by a shorter cut.

The author has not observed any examples of the diversion of streams by glacier action in the valley of the Rother.



MAP
OF THE
DON RIVER-SYSTEM.

Proc. Yorks. Geol. Soc., Vol. XV., Plate LIII.

THE GLACIATION OF THE DON AND DEARNE VALLEYS.

BY W. LOWER CARTER, M.A., F.G.S.

In studying the physical geology of the Don River-System,* my attention was specially directed to the evidences of glacial action in that area, with the object of ascertaining whether glaciation had anything to do with the interesting diversions of the Don, Dearne, Dove, and Rother. Certain valleys also attracted my attention as exhibiting abnormal features with respect to the present drainage of the district, and there appeared to be two or three cases of glacial diversion of streams, which necessitated an inquiry as to what their relations might be to the altered conditions which a period of glaciation would have produced.

The present paper is an attempt to piece together these scattered fragments of evidence into a continuous glacial story, and the result indicates a phase of glaciation subsequent to the chief work of the erosion of the Calder Valley by the overflows of the Burnley and Summit (Todmorden) gorges, and prior to the formation of the York and Escrick moraines. The work of denudation over the valley of the inner Don and Dearne appears to have been so severe that the evidence has in a large degree been removed, whilst the central Triassic plain is such a complex of deposits that it may need years of careful work before its conflicting evidence can be reconciled. This paper does not attempt to deal with the glacial evidence beyond Balby. The area dealt with has been so fully described in the author's paper on the Evolution of the Don River-System* that there is no need to refer to it here any further.

The glacial evidence has been gathered from the Geological Survey Memoir on the Yorkshire Coal-field, and from the careful descriptions added to each patch of gravel marked on the six-inch geological maps. The valuable reports of the Yorkshire Boulder Committee have furnished important facts, whilst the author has taken opportunities of going over portions of the ground

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* See p. 388.

with experienced local workers, including Mr. Walter Hemingway, of Barnsley, and Messrs. H. H. Corbett and H. Culpin, of Doncaster. To Professor P. F. Kendall the author is deeply indebted for much valuable criticism and helpful advice.

I.—The Glacial Deposits.

(1) *Staincross.*

Professor Green describes a section in a railway cutting at Staincross,* about two miles north of Barnsley, showing forty feet of stiff boulder-clay, filling up a hollow excavated in the Woolley Edge Rock of the Middle Coal Measure series. The surface of the sandstone at the face of junction he found to be much shattered and smashed, large blocks of sandstone being wrenched off and imbedded in the clay. The clay was divisible into two beds (Pl. LIV.). The lower contained large quantities of Coal Measure rocks, chiefly sandstones, with fragments of well-scratched shale and pieces of coal. Foreign rocks were also found, including Carboniferous Limestone (ice-scratched), chert and black earthy limestone, and a piece of blue closely-grained trap, with crystals of iron pyrites. Overlying this lower clay and sometimes dovetailing into it, were seams of warp, bluish-brown in colour, finely laminated, but with wavy and irregular bedding, and containing well-rounded pebbles of Carboniferous sandstone and bits of coal. Over these comes an upper clay, more sandy in texture, with lenticular sheets of sand and gravel, and irregular interbedded masses of warp, rudely bedded, and in places sharply contorted. This clay is traversed by cracks with polished faces filled in with sand.

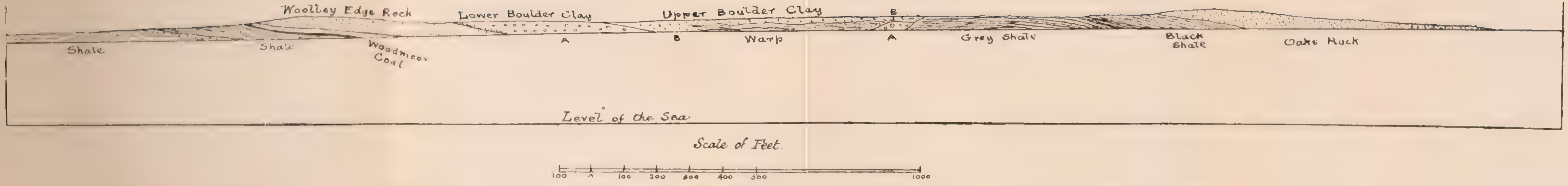
(2) *Royston and Carlton.*

This boulder-clay appears to extend E. and N.E. to Carlton and Royston (Fig. 4), and the whole country for some square miles is strewn with glacial relics.† The geological surveyors have recorded a large boulder of shap granite at Royston‡ (Plate LV.) and a boulder of syenite at Notton Green (170 feet

* Mem. Yorks. Coal-field, p. 776.

† T. Tate, F.G.S., Yorks. Boulder Report, 1894.

‡ Now in Barnsley Park.



Proc. Yorks. Geol. Soc., Vol XV., Plate LIV.

SECTION IN THE CUTTING OF THE MINERAL RAILWAY, TWO MILES NORTH OF BARNSLEY (STAINCROSS).

Copied from "The Geology of the Yorkshire Coalfield," p. 778, by permission of the Controller of H.M. Stationery Office.

O.D.). In addition Mr. Tate found at Royston boulders of Armboth felsite, Threlkeld micro-granite, diabase, andesitic ash and volcanic breccia. To this list Mr. Hemingway adds rhyolite, rhyolitic breccia, vesicular lava, olivine basalt, Carboniferous Limestone, flint, and fossiliferous Lias.

In 1904 a main drain was taken down Carlton Bank, which revealed many boulders of the above type.

About half a mile south of Carlton (junction of sheets 262 and 274) Professor Green describes a section* in which the Oaks Rock, dipping N.E., is covered with "blue clay, very stiff, somewhat gritty, without a trace of bedding (Fig. 1). Pebbles and blocks of Carboniferous rocks, mostly small, but here and there a large block ; many flat bits of black shale,

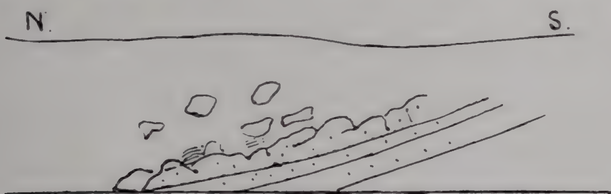


Fig. 1.

SECTION SOUTH OF CARLTON, SHOWING BOULDER-CLAY ON OAKS ROCK (A. H. GREEN).

rounded at the edges and thickly covered with ice-scratches. The shales very abundant and every bit scratched on all sides ; coal ; Mountain Limestone, ice-scratched ; yellowish soft limestone, perhaps Magnesian ; white altered flint or chert ; blue close-grained trap, with small crystals of pyrites ; earthy limestone, probably Yoredale."

(3) *Barnsley.*

During the excavation for the Barnsley gasometer the following section (Fig. 2) was discovered and is recorded in Professor Green's notebook, from which I was permitted to copy it by Mrs. Green's kindness :—

(1) Pale grey shale, with occasional nodules of ironstone. At one place there are little troughs of gravel in the top of this bed.

* Extracted from his notebook by the kind permission of Mrs. Green.

Fig. 2.

SECTION IN THE EXCAVATION FOR A GASOMETER, BARNSLEY GASWORKS, OLD MILL, BARNSLEY, MARCH 28TH, 1885 (PROF. A. H. GREEN).

(2) Pale grey clay, obviously (1) ground up. No stones or pebbles. It is simply weathered or ground up shale ; there is no hard line between it and (1). In some places the bed above (4) seemed as if it sent tongues down beneath this bed. In some places it looked as if this bed had been crushed up into heaps, leaving spaces where it was absent between the heaps.

(3) Rough dirty sandstone gravel.

(4) Stiff clay, many angular blocks of C.M. sandstone and galliard ; one of trap. The blocks are very angular ; some looked ice-worn. It looks ice-formed, and the way in which it is thrust in tongues into (2) suggests the action of ice.

(5) Rough dirty sandstone gravel.

(6) Sandy clay ; wood and patches of carbonaceous clay with leaves and nuts towards the bottom.

The following is an extract from Mr. Walter Hemingway's (Barnsley) letter of April 6th, 1885, to Professor Green about the above section :—

" Referring to the excavation at Old Mill Gasworks, I looked over the material at the ' tip ' after Thursday morning's rain, and found the gravel (3) which had come from between the stony clay and the fine blue clay at bottom of section to contain a fair quantity of foreign rocks, chiefly dark greenish fine-grained trap."

(4) *Burton Grange, Ardsley, and Adwick-on-Dearne.*

A patch of boulder-clay was found near Burton Grange containing Carboniferous Limestone, granites, rhyolites, and basalts. At Ardsley Hill a similar clay is recorded by Mr. Hemingway* as containing Borrowdale andesites, St. John's Vale microgranite, rhyolites, Carboniferous and Permian limestones, gannister, &c.

At Adwick there is a patch of boulder-clay at 150 feet, containing Carboniferous sandstone, quartzite, felstone, and encrinital chert ; in close proximity to which was a boulder of Shap granite (Plate LV.).†

* In a letter to the author.

† Now at the Sheffield Public Museum. Unfortunately before its removal to Sheffield several large pieces were broken off by a marauding Philistine to ornament a rockery.

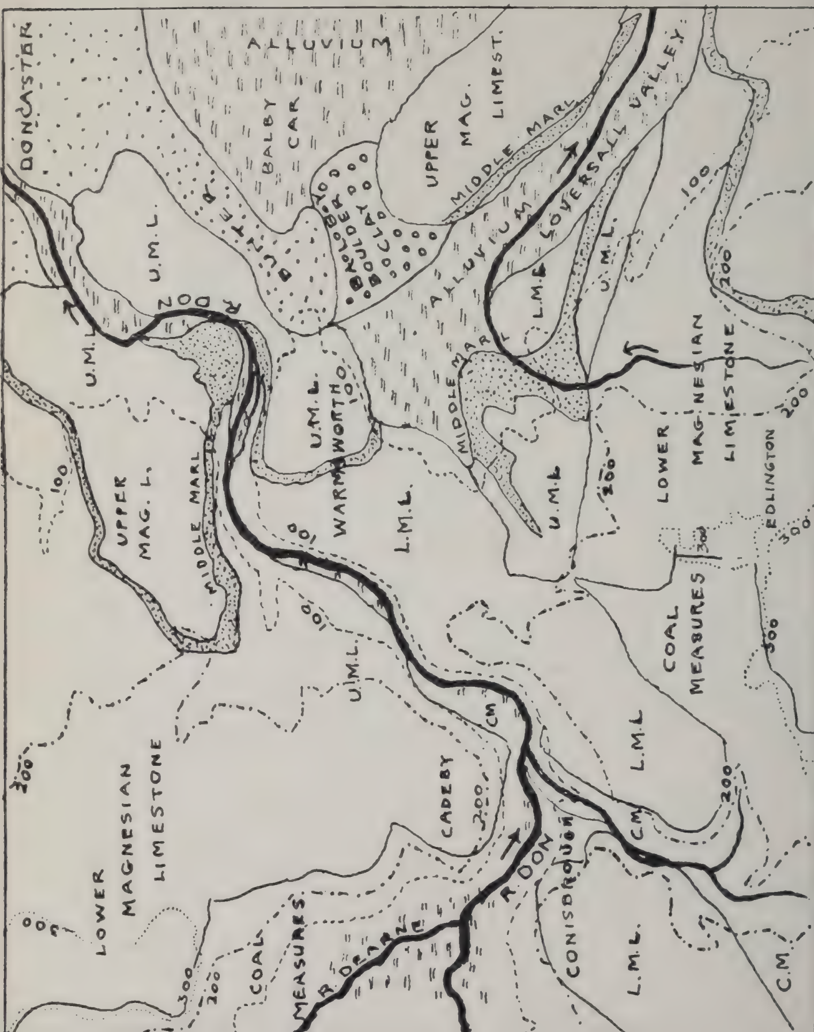


Fig 3.

MAP SHOWING THE RELATION BETWEEN THE DON, BALBY, AND LOVERSALL VALLEYS.

U.M.L. = Upper Magnesian Limestone.
L.M.L. = Lower Magnesian Limestone.
C.M. = Middle Coal Measures.

In the railway cutting west of Conisbrough station Professor Green records* Coal Measures overlaid by sandy rainwash, with rubble and large blocks of Magnesian Limestone and coal smut. At Conisbrough, near the station, boulder-clay was seen by Mr. H. H. Corbett in the foundations of some houses.

At the Ashfield Brick Works, at the 225-foot contour, there is a patch of drift containing Magnesian Limestone, Carboniferous Limestone, and Lake Country andesites. The deposit overlies Lower Permian Marls, which are much contorted, and the Middle Coal Measures. On the opposite side of the Don gorge, at Cadeby, a similar deposit has been recorded by Messrs. Corbett and Culpin in a railway cutting, including boulders of andesite, Mountain Limestone and Magnesian Limestone. There is a general accordance in the facies of these

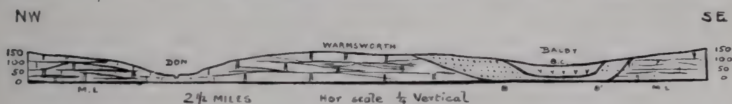


Fig. 4.

SECTION ACROSS THE DON GORGE AND THE BALBY BRICK PITS.

M.L. = Magnesian Limestone. B. = Bunter. B[1] = Not exposed, Bunter inferred. B.C- = Boulder Clay.

deposits, corresponding to the upper clay of Staincross, and linking it on to the remarkable boulder-clay deposit of Balby, near Doncaster, and the author proposes to explain them as the relics of the Stainmoor glacier, which he believes to have extended thus far at one stage of the Glacial Period.

The Balby section is the most remarkable deposit of boulder-clay in the district (Plates LVI., LVII., LVIII.). It forms an isolated patch about one mile long and half a mile wide, with its long axis running nearly east and west (Fig. 3). It is bounded on its northern side by Bunter sandstone, which also is found to underly it wherever the base is seen. The underlying surface of the Bunter is water-worn, and the junction is clean, without any intermediate warp or gravel (Plate LX., Fig. 1). The Bunter itself appears to fill up a pre-Triassic valley in the Magnesian

* From his notebook, by kind permission of Mrs. Green.

Limestone (Fig. 4), and to have been re-excavated by a small stream flowing from Conisbrough Park and Edlington in pre-Glacial times. The boulder-clay is a stiff brownish or bluish till, about forty feet in thickness, crowded with large and small erratics, which thins away northwards to three feet in Wood's pit, lying on an uneven surface of Bunter sandstone. During the excavations for the Doncaster Workhouse the section was well exposed. "The clay was seen to rest upon the sandstone at angles varying from 40° to 10°, the steeper angles being at the western end, and the slope being from north to south. In some sections large angular fragments of the sandstone were seen imbedded in the clay (Plate LIX.)."* In this deposit a remarkable assemblage of travelled boulders has been found, including Shap granite, Threlkeld microgranite, Borrowdale andesite and andesitic agglomerate, Eycott Hill diabase, Eskdale granite, and a schist with garnets.† Carboniferous limestones and cherts are common, many being highly fossiliferous, and Millstone Grit and material from the Lower and Middle Coal Measures are very common. Lumps of Permian marl and blocks of fibrous gypsum are plentiful, as are blocks of Magnesian Limestone, "a large percentage of which contain casts of *Axinus*, *Mya*, *Turbo*, &c. The fossil bed whence they are derived crops out near Hampole, and at several other places along the escarpment of the Magnesian Limestone, e.g., Conisbrough and Clifton."‡ Mr. Corbett reports finding this bed cropping out at Hooton Pagnell on the west side of Frickley gorge, where it is about 15 feet thick.||

In the neighbouring Don gorge drifted gravels have been found near Sprotborough up to 150 feet on the Limestone. "At Cusworth boulders up to a ton in weight are turned up in the fields by ploughing. These consist of grits, ganisters, Mountain Limestone, Whin Sill, quartz porphyry, and basic rocks."§

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* H. H. Corbett, Glacial Geology of the Neighbourhood of Doncaster, Naturalist, 1903, p. 47.

† Supposed by the author to be Scotch.

‡ H. H. Corbett, see ante, p. 49.

|| H. H. Corbett, Report Yorks. Boulder Com., 1900.

§ H. H. Corbett, Naturalist, 1903, p. 49.

Photographed by W. E. Brady, Barnsley.

Fig. 1.

BOULDER OF SHAP GRANITE FROM ROYSTON, NOW IN BARNSLEY PARK (WEIGHT ABOUT 30 CWT.).

Photographed by C. Bradshaw.

Fig. 2.

BOULDER OF SHAP GRANITE FROM ADWICK-ON-DEARNE, PRESENTED BY EARL MANVERS TO THE SHEFFIELD PUBLIC MUSEUM (WEIGHT 7¼ CWT.).

At Hexthorpe Flats, near Doncaster, there is a section of a thin bed of boulder-clay on false-bedded Magnesian Limestone. In the pit is a large boulder of striated Carboniferous Limestone. Blocks of basalt have been obtained from excavations in Doncaster. Up the slope of the Magnesian Limestone and Coal Measure shales forming the southern side of the gorge of the Don, drifted pebbles and lumps of red marl have been found at elevations up to 300 feet at Edlington (Fig. 9), and scattered quartz and sandstone pebbles and limestone fragments are found scattered over the limestone at Clifton and Braithwell up to 400 feet.

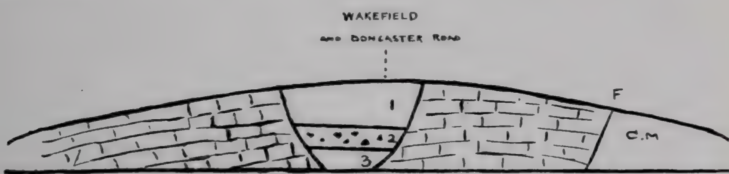


Fig. 5.

SECTION IN RAILWAY LINE NEAR HAMPOLE STUBBS.

Length 200 yards. Greatest height 20 feet.

1. Stiff Brown Clay, no boulders, 10 feet.
2. Boulder Clay, 4 feet (Magnesian Limestone and Coal Measure Sandstone).
3. Yellow Marl, 5 feet (re-assorted Magnesian Limestone).

Between the Dearne and the Hickleton escarpment the evidences of glacial action are few and far between, but the Survey Memoir* records boulder-clay east of Emsall Lodge containing pebbles and boulders of Carboniferous sandstone, quartzite, and encrinital chert. Mr. E. Leonard Gill, B.Sc.,† found a section on the new railway line near Hampole Stubbs (Fig. 5) where the Doncaster road crosses the line, which showed the following succession :—

1.—Stiff brown clay, no boulders... .. 10 feet.
2.—Boulder-clay, containing pebbles, fragments, and rounded boulders of sandstone and Magnesian Limestone .. 4 feet.

* See p. 777.

† Communicated by Professor Kendall.

3.—Yellow marl .. .. 5 feet.
4.—Magnesian Limestone .. .. ..
5.—Coal Measure sandstone and shale ..

Still further north the escarpment of the Magnesian Limestone from Went Bridge to Pontefract and Glass Houghton shows extensive denudation, and is covered with pebbles of Carboniferous sandstone.

There is another series of gravel and clay beds in this area which seem to agree together and to be parallel with the lower clay of Staincross (Plate LX.). One mile west of Darfield* there is a patch of gravel containing pebbles of Carboniferous sandstone, quartzite, chert, and Magnesian Limestone. At Wombwell, near the 310-foot contour, there is an angular block of ganister. At Park Hill, near Wombwell, in the valley of the Dearne, is a gravel with large boulders of Carboniferous sandstone. At Barbot Hill, near Parkgate, is a clay with quartz pebbles, sandstone, Carboniferous Limestone, Oolitic rocks, and Magnesian Limestone, covering the hill at 200 feet above O.D. At Sitwell Vale, south of Rotherham, is a patch of clay filling up the end of a little valley, with Carboniferous sandstone boulders. At Hooton Roberts there are four patches of gravel resting on Coal Measures from 200 feet to 250 feet above O.D., containing Carboniferous sandstone, quartz, quartzite, and black chert.

I have ventured to link these deposits together as having a common origin, which I attribute to an earlier glacier bringing mostly Carboniferous rocks, and agreeing with the Pennine ice of the Vale of York. The rare pieces of oolite may be due to material carried by icebergs, and caught up by the glacier in passing, and the predominant Coal Measure material and the Magnesian Limestone are probably due to the denudation of the Pontefract district as the glacier passed over the Aire. These patches appear to be the mere remnants of much more widely spread deposits, and I attribute the perfect preservation of the three boulder-clay deposits at Staincross, Balby, and Hampole to the fact that in the case of each of them the glacial detritus has filled up a little pre-Glacial valley which on the resumption

* Memoir on the Yorkshire Coalfield, p. 777.

of ordinary conditions was out of the line of stream denudation, and thus their contents have been preserved intact.

The Rev. C. T. Pratt, M.A., records a boulder of volcanic ash, weighing 3 cwt., from Rawgreen, a quarter of a mile west of Cawthorne, at the 300-foot contour. Also a larger boulder of volcanic ash from Banks Bottoms, Nobelthorpe.* These I should explain as conveyed from the Staincross glacier-lobe by icebergs. The scattered pebbles of foreign rocks, many resembling compact slate rocks or jaspers, and the boulder near Renishaw, recorded by Dr. Clifton Sorby,† from the valley of the Rother, could also be accounted for by the agency of small icebergs from the glacier which closed the mouth of the Rother.

I have not attempted to explain or to include in the present survey the puzzling, isolated patch of boulder-clay with Lake Country erratics found at Crosspool, at an elevation of 730 feet west of Sheffield. I believe this will be found to be a relic of another phase of the Glacial Period than the one I have described here, and may be found to link on to the Crich Stand and other southern patches of boulder-clay at much greater elevations than those of the Don and Dearne.

II.—Conditions of Formation.

To explain the conditions of the formation of these puzzling deposits one must turn to the Vale of York, and try whether the drifts of the Don area can be linked on to those north of the Aire. Stretching across the Vale of York in a semi-circular curve, which passes through York, is a line of mounds which was recognised by Professor Carvell Lewis‡ as the terminal moraine of a glacier advancing from the north. Parallel to this moraine is another and parallel ridge passing through Escrick, about five miles south of York. This Professor Kendall described|| as a second terminal moraine of the same glacier. The left lateral moraine of this glacier has been traced along the western

* Report Yorks. Boulder Com., 1896-97.

† Letter to Professor Green, January 7th, 1868.

‡ Glacial Geology of Great Britain, p. 30.

|| Proc. Yorks. Geol. and Polytec. Soc., XII., 310.

flanks of the Hambledon and Cleveland Hills, rising from 200 feet at Sheriff Hutton to 400 feet near Thirsk and 600 feet at Northallerton. This moraine contains Shap granite, Lake Country rocks, and other erratics characteristic of the Stainmoor glacier. On the other hand, the right lateral moraine, which extends along the lower slopes of the Pennine Chain by Knaresborough and Fountains Abbey, to Masham, contains Carboniferous Limestone, Yoredale limestones, and cherts, and other erratics characteristic of the Pennine valleys, and especially of Wensleydale. There is a medial moraine passing from Allerton Park in a north-westerly direction to Bedale and Richmond, which shows the characteristic features of medial rock trains, being a union of the rock trains of the converging glaciers. Accordingly we find that the erratics on the western side of this medial moraine are of the Pennine type, whilst those on the eastern side belong to the Stainmoor series. This appears to me to be the key to the Don and Dearne problem. The excellent definition of the glacial phenomena up to York, compared with the lack of definite features southwards, led the late Professor Carvell Lewis to terminate the glacial advance at that city, and to explain all the southerly drift deposits by a great lake and iceberg carriage. But I make bold to say that if there is a deposit of land-ice Till in Yorkshire it is at Balby, and that the Staincross section can only be explained by glacier action on the spot. The more the glaciation of England is studied the more thoroughly does the conviction come home that there have been many and varying conditions successively existing over the same area, and therefore lake conditions at one period do not exclude land glaciers at another over the same district. Professor Carvell Lewis subsequently notes* that he had found traces of a much older series of glaciers, more extensive than those so plainly indicated by their moraines, the relics of which had been largely removed, the striæ obliterated, and the area reduced to the appearance of a non-glaciated district. This is the conclusion to which I had been forced in the Don area before I saw the above note, and it is to the extension of the Wensleydale glacier, reinforced it may be by the Nidderdale,

* Glacial Geology of Great Britain, &c., p. 60.

Photographed by R. A. Bellamy, Doncaster.

Fig. 1.

Photographed by R. A. Bellamy, Doncaster.

Fig. 2.

SECTIONS OF BOULDER-CLAY, BALBY, NEAR DONCASTER.

Photographed by R. A. Bellamy, Doncaster.

SECTION OF BOULDER-CLAY AT BALBY, NEAR DONCASTER (SHOWING PARTING OF SAND).

Proc. Yorks. Geol. Soc., Vol. XV., Plate LVII.

Photographed by R. A. Bellamy, Doncaster.

Fig. 1.

The large boulder is Coal Measure Sandstone, and measures about 4 ft. × 2 ft. 5 in.

Photographed by R. A. Bellamy Doncaster.

Fig. 2.

The boulder in the foreground is Lower Magnesian Limestone, and is the largest that has been found at Balby. Size, 6 ft. × 4 ft. × 3 ft.

BOULDERS FOUND IN THE BALBY BOULDER-CLAY.

Photographed by R. A. Bellamy, Doncaster

Fig. 1.

BOULDER-CLAY, DONCASTER WORKHOUSE, BALBY.

Showing a mass of Bunter Sandstone dragged up from below and incorporated with the Till. The word TRIAS is scratched on the Bunter Sandstone.

Photographed by R. A. Bellamy, Doncaster.

Fig. 2.

JUNCTION OF BUNTER SANDSTONE AND BOULDER-CLAY AT DONCASTER WORKHOUSE, BALBY.

Wharfedale, and Airedale glaciers, that I would attribute the first phase of glaciation in the Dearne and Don, followed by a glaciation by the Stainmoor ice, and associated with a complicated series of glacier lakes.

The succession of phenomena suggested is as follows:— In the early stages of the Glacial Period Yorkshire seems to have stood 200 feet higher than at present, for along the great Triassic valley, stretching from Newcastle to the Midlands, there is a drift-filled hollow* which at Gateshead is 140 feet, at Cawood 74 feet, and at Barnby Dun 170 feet below O.D. With the lowering of the temperature at the commencement of the Ice Age, the Highlands of Scotland, the Cheviots, the Lake and Welsh Mountains, and the Pennine Chain would be centres of great snow-precipitation, and would give rise to glaciers radiating by the principal valleys from their snow-fields. As the cold became more intense these local glaciers would be augmented, and spreading out fanwise in the plains would become confluent. By this means it is probable that before the Norwegian ice began to make its influence felt on our coast-line the vales of Mowbray and York would be choked with ice from the valleys of the Pennine Chain. When by the interference of the Scandinavian ice the Scotch glaciers were deflected into the Irish Sea and down the Northumberland and Durham coast, the ice-stream overflowed from the Vale of Eden by Stainmoor Pass into Teesdale. At first it found free access seawards by Teesmouth, but then, obstructed in its turn by the Scandinavian glacier, was forced to overflow, all way of escape northwards being blocked, through the wide gap between the Cleveland Hills and the Pennine Highlands into the plain of Mowbray and York. This Stainmoor glacier was evidently large and powerful and able to thrust aside and over-ride the Vale of York ice, and, preventing all further eastward flow of the Pennine glaciers, crowded them back against the lower slopes of the Pennine Chain. Thenceforward it would appear that the two ice-streams moved in parallel lines as far as Airedale, where the Pennine ice, yielding to the vigorous thrust of the Stainmoor glacier, was forced into

*P. F. Kendall, Proc. Yorks. Geol. and Polytec. Soc., XV., 1.

the wide embayment of the Aire and Calder, bending back the Airedale glacier and moving southwards through Frickley gorge into the Dearne valley. As the lateral pressure of the Stainmoor ice increased. the Pennine stream would spread out south and west, wearing back the Magnesian Limestone escarpment, eroding the soft Middle Coal Measure shales between Frickley and Conisbrough. and pressing against the higher land on the southern side of the Don, probably sent a tongue of ice through Conisbrough gorge into the plain at Doncaster. Meanwhile westwards the low watershed between Clayton and Notton would be surmounted. the ice pressing on to Staincross and Ardsley, and southwards to Rotherham. This would constitute the first glacial invasion of the Don and Dearne, and its moraine would be largely composed of local Coal Measure detritus with some Magnesian Limestone. and with an admixture of Carboniferous Limestone and chert boulders. Subsequent denudation would leave mere fragments of these glacial deposits. Then there would appear to have been a partial retreat of the Pennine ice northwards. but with no corresponding diminution of the Stainmoor glacier. but rather an increase, which enabled it to press over the Permian escarpment, probably over-riding the lobe of Pennine ice in the Conisborough gorge, and successively taking the place of the Pennine glacier as it retreated, until the Stainmoor ice apparently reached its maximum extension in this area along the line of the Dearne from Barnsley to Adwick and on to Conisbrough.

In order to explain this retreat I would suggest that as the Irish Sea became choked with ice the line of maximum snow-precipitation would slowly be shifted westwards from the axis of the Pennine Chain, and therefore that there would gradually be a lessening of the snowfall that fed the glaciers in the Pennine valleys sufficient to cause an arrest of the advance of the Pennine ice, and ultimately to necessitate its slow retreat. The pressure of the Scandinavian ice, however, would be in no wise relaxed, and the continued crowding of the Scottish ice westwards by its strenuous thrust would render the Irish Sea more and more thoroughly choked, and hence the necessity of an escape over Stainmoor more continuous. Thus the Stainmoor glacier would increase as the Pennine ice decreased.

This invasion of the Don-Dearne area would necessarily deflect the Calder southwards, and impound the considerable drainage of the eastern slopes of Wharncliffe Chase and the ridge northwards to Hoyland Swaine, and a lake or lakes would be formed. The next section is an attempt to outline these lakes, and to indicate their lines of overflow at successive periods.

III.—Glacier Lakes.

Are there any evidences of the existence of such glacier lakes in the Don-Dearne area, and, if so, can we identify their boundaries and locate the channels by which they were drained? This is a difficult problem, as the whole area lies comparatively low, and appears to have undergone an enormous amount of denudation, as is indicated by the widely-scattered erratics and the comparative absence of boulder-clays. That there must have been such a closing of the Don gorge as would produce a great lake is indicated by the glacial drift at Ashfield and Cadeby at the 225-foot contour on opposite sides of the gorge near Conisbrough, showing that ice must have filled the gorge at least up to that level. Hampole gorge being then covered by ice, a great lake would be formed, having its ramifications far up the valleys of the Don, Dearne, Sheaf, and Rother. We can hardly in the nature of things expect much evidence of lake deposits in this area, but, in addition to the warp in the Staincross section, the Geological Surveyors report 4-9 feet of brick-earth and clay on gravel at Parkgate in the Don valley, and of 3-7 feet of brick-earth at 90 feet O.D. at Wombwell, in the old Dove valley; also a considerable thickness of silt covering vegetable matter and sand was found at the Old Mill section, Barnsley, in the Dearne valley. In addition to these warps there are widely-spread deposits of yellow clay, which may be partly decomposed shale and limestone, partly residual boulder-clay, and partly also lake warp.

In commencing the study of this area my attention was at once attracted by certain valleys which appeared to be out of the line of drainage, and which traversed significant lines of watershed. They were mostly strike valleys, and therefore liable to suspicion, but, seeing that the glacial advance, as indicated by the drift, appears to have been parallel to the strike, it would seem certain by the geological structure of the country that any lake overflows would necessarily be found along the lines of shales between prominent sandstone beds. The cols naturally made by sub-aerial denudation would form natural channels of escape, and the overflow streams would quickly cut down such cols into long strike valleys. The valleys are not, and I do not think they can be expected to be, of the Cleveland type. The latter are probably the last relics of the retreating ice-sheets from Yorkshire, and are at sufficient elevations to be fairly preserved from rapid subsequent denudation. Hence they retain their sharpness of slope and definition of outline. On the other hand the Don-Dearne valleys must have belonged to a much earlier phase of glaciation, and the contours being low, and the whole area having again and again been invaded by lakes and inundations of water, have suffered so considerably as to modify in a great measure their glacial outlines. The streamless parts of these valleys, however, do not appear to have been much lowered, although the sides have been worn back considerably by subærial denudation, and hence the cols will indicate pretty nearly the levels of glacial overflow. The courses of neighbouring streams being independent of these valleys, seem to imply that their formation has been quite apart from the present drainage system.

In order to check these points with all possible care, the drift patches were taken as indicating lines of moraine, and therefore of glacial rest, and the results of the obstruction of the drainage by a glacier along each of these lines was plotted on the six-inch ordnance contour map, and the lakes outlined that would be produced by such obstructions of the drainage. As this work was done an overflow channel was found, corresponding to each lake.

The first invasion of the ice would probably be through Frickley gorge into the low-contoured area between Darfield and Hickelton, the present flatness of which may be greatly due to the scouring of a long period of glacial occupation.

This tongue of ice would dam back the Dearne at Frickley gorge,* causing the formation of a lake at Thurnscoe (Fig. 6), which appears to have overflowed along the northern edge of the outcrop of the Upper Chevet Rock, and excavated the valley to the north of Bolton-on-Dearne, falling into the Dove at Adwick.† A slight advance seems to have closed the Bolton valley, and caused the lake to overflow and cut a notch through the Upper Chevet Rock at Carr Head. A further advance was checked by the higher land at Darfield (Fig. 7), and the waters of the

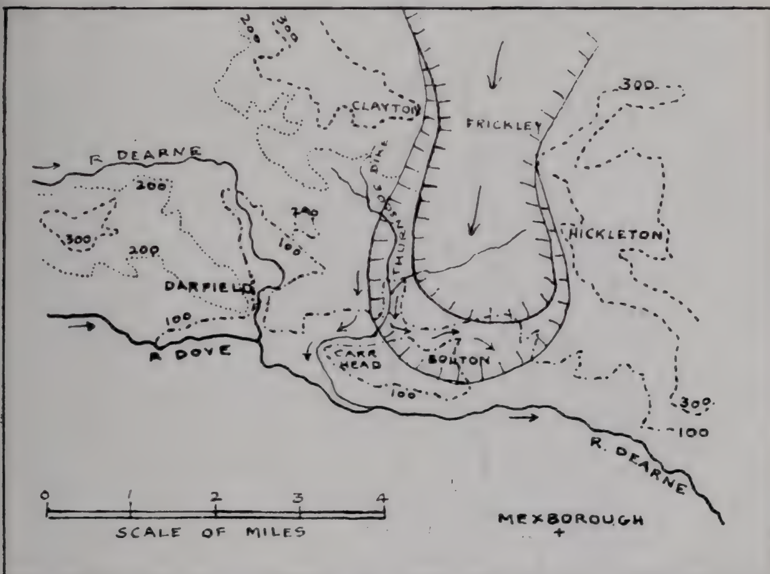


Fig. 6.

DIAGRAM OF THE ICE-FRONT WHEN THE BOLTON-ON-DEARNE AND CARR HEAD CHANNELS WERE FORMED.

Dearne, forming a lake reaching up to Ardsley and Barnsley, were probably reinforced by the diverted drainage of the Calder, which would escape over the low watershed at Notton (Pl. LXI.). Thus there would be a considerable current of water available for the cutting of Darfield gorge, which has every sign of comparatively

* See previous paper, p. 403.

† See also Fig. 6, p. 404

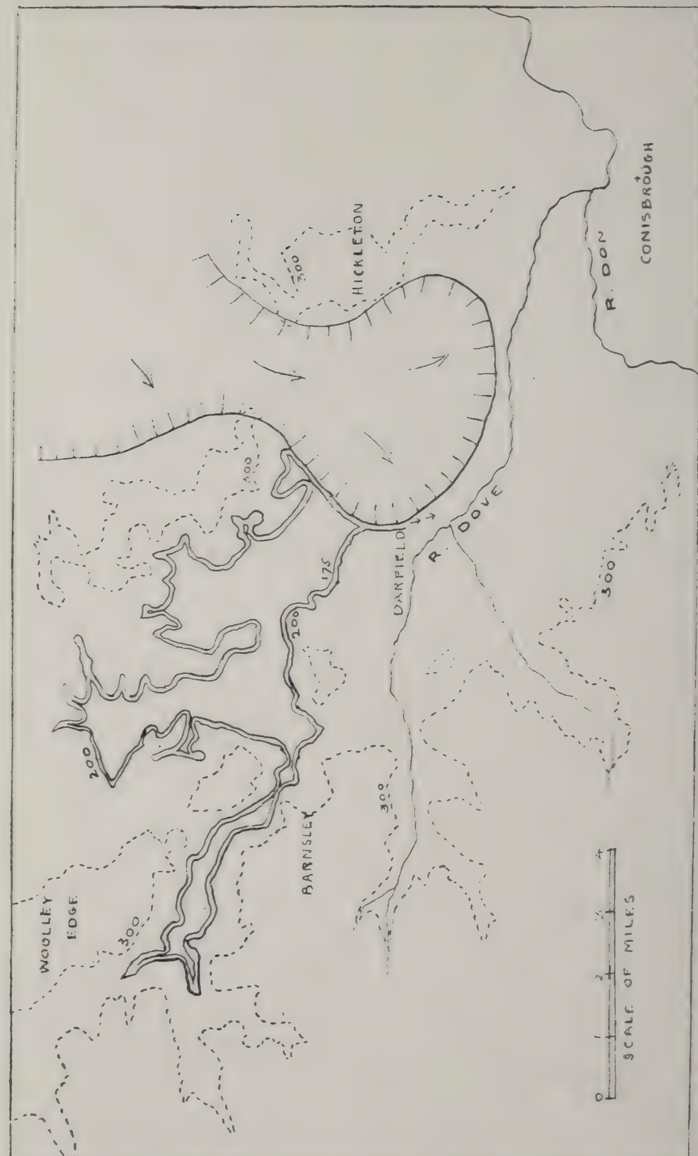


Fig. 7.

DIAGRAM TO EXPLAIN THE FORMATION OF DARFIELD GORGE.

recent and rapid erosion. The ice-front remained sufficiently long at this point to allow of the gorge being cut more deeply than any of the adjoining valleys, and thus at the close of the Glacial Period it became the permanent course of the Dearne. The part of the old Dearne valley from Great Houghton to Frickley being thus left high and dry by the deflection of the Dearne at Darfield, became part of the low watershed of a little beck, Thurnscoe Dike, which found an easy escape by the notch (75 feet) at Carr Head, which had been cut lower than the Bolton valley (93 feet), and so became the permanent channel of this little stream, giving it the sharp bend that looks so curious on the map.

A further advance of the glacier to the line joining Ardsley, Darfield, and Adwick would close the Dearne at Ardsley, and form a lake which we may call the Barnsley lake (Pl. LX., and Fig. 8), which would overflow by the col at Stairfoot, at the 175-foot contour. A further advance to Wombwell and Swinton would dam the Dove and cause the Barnsley lake to enlarge into Worsborough Dale, and rise to the 270-foot contour, when it would overflow by the Wombwell valley. This is a strike valley excavated in the shales between the Oaks and the Woolley Edge Rocks. The little stream which flows out of the valley northwards into the Dove rises to the west in Wombwell Wood, flows over the Woolley Edge Rock across the dip, and only follows the strike when it reaches the valley. It can have had no part in excavating the central part of the valley, which is flat and streamless. Continuing the direction of the Wombwell valley south-eastwards, there is another strike valley west of Swinton also excavated in the shales underlying the Oaks Rock, the central part of which is streamless, and forms a col at the 225-foot contour which held up the overflow from the Barnsley and Worsborough Lake, forming a Swinton Lake at that level. The overflow from this lower lake would reach the Don by way of Kilnhurst.

In considering the further advance of the glacier to the Barbot Hill, Masbrough, and Sitwell Vale drifts, the author could not avoid the conclusion that it would press over the advanced spur at Stubbin (Plate LX.) up to, say, the 350-foot contour.

This would cause the impounding of the whole northerly drainage as far as Bretton, and would have united the three lakes into one large lake. This would have been an impossibility unless an outlet existed to carry off the overflow. No such valley was up to that time known to me, but the six-inch maps of the Wentworth area being obtained, a cut was found through the 350-foot

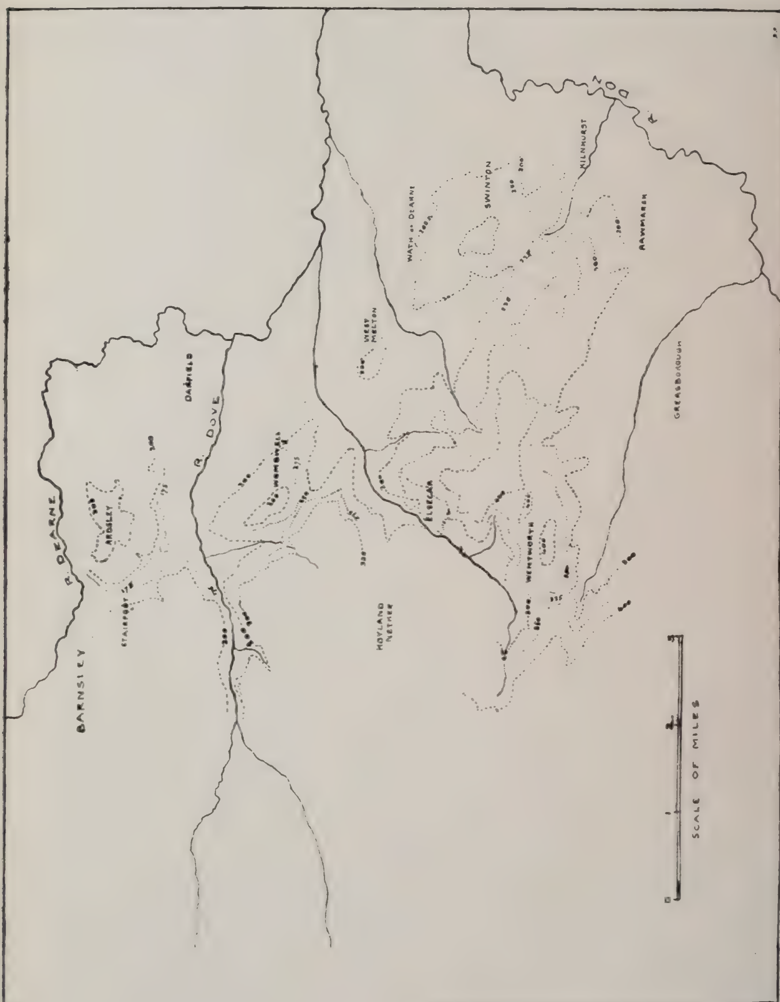
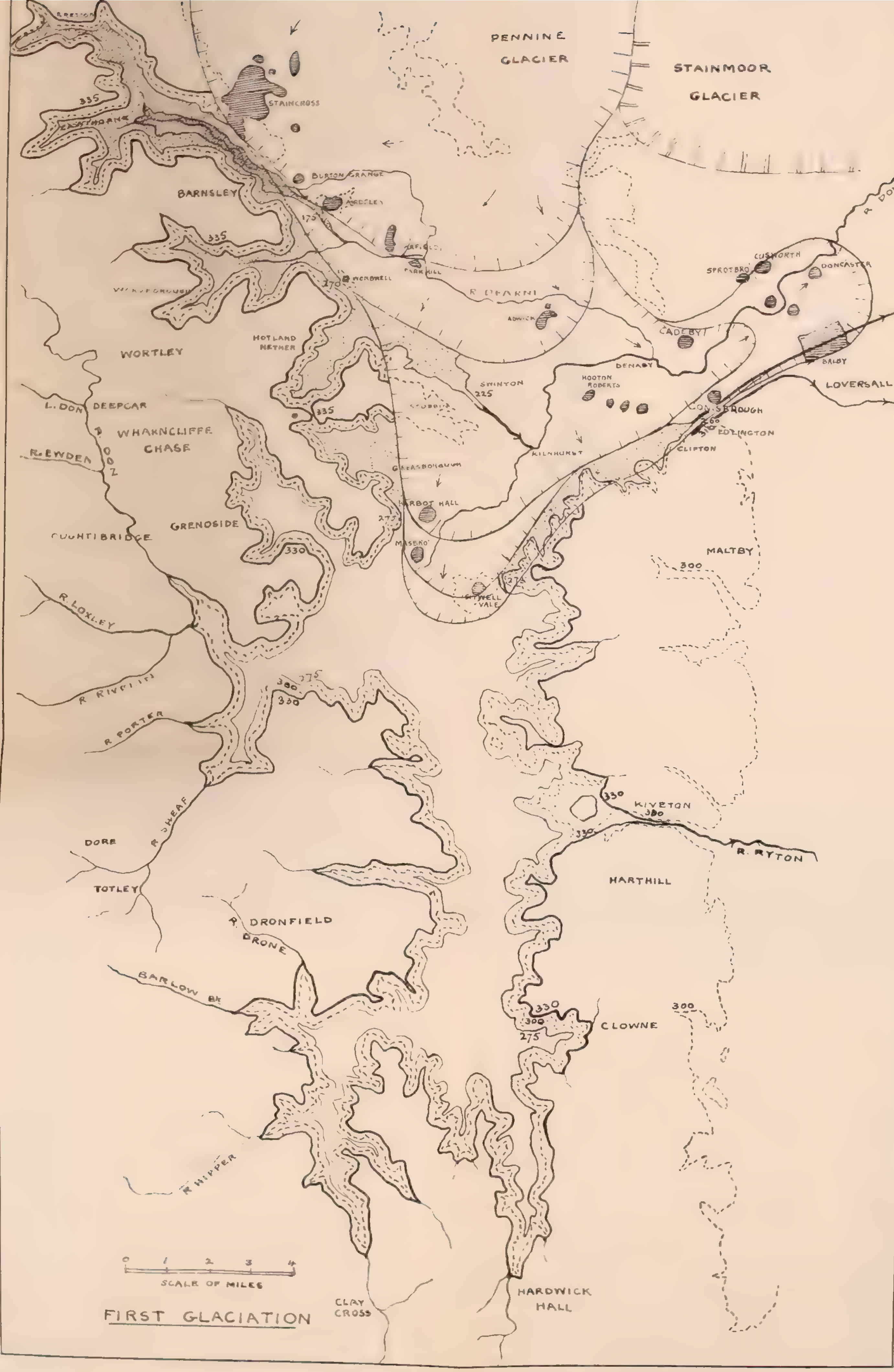


Fig. 8.

THE OVERFLOW CHANNELS SOUTH OF BARNSLEY.



Proc. Yorks. Geol. Soc., Vol. XV., Plate LX.

MAP OF THE SUGGESTED ADVANCE OF THE PENNINE GLACIER SHOWING THE LAKES FORMED AT THE VARIOUS LINES OF ADVANCE UNTIL THE CONISBROUGH GORGE WAS CLOSED AND LAKE DON (330 FEET O.D.) WAS FORMED.

contour, forming a little flat valley about a quarter of a mile wide between Higher Stubbin and Wentworth, at the level of 335 feet above O.D. This seemed to be an important demonstration of the stability of the methods of investigation, and is confirmed in an interesting way by the level of Kiveton gorge, which appears to be the final outlet of the great Don lake, being at 330 feet above O.D.

The Wentworth overflow (Fig. 8) is a little strike valley cutting through a narrow watershed, with a marked escarpment on the eastern side, where there is the outcrop of a grit bed, and a smooth slope on the western side. But the present drainage has no relation to this gap, and could not have formed it. The stream at the northern end, which runs by Elsecar, rises some distance to the west of the gap, and flows directly across its end. The same is true of the drainage of the Wentworth Woodhouse valley.

When the glacier front thus extended from the spur at Stubbin to Barbot Hill, the drainage of the lake impounded in the Wentworth Woodhouse valley would flow along the ice-front, and there is a notch at 203 feet west of Masbrough which would represent this stage. When the ice lobe reached Masbrough and Sitwell Vale the Rother would be dammed, and we find a notch about a mile south-west of Greasbrough at 275 feet which would drain the western lakes into the Rother, and another dry valley east of Sitwell Vale, also at the 275-foot contour, which would take the overflow of the lake formed by the impounded drainage of the Rother, a lake which would stretch as far as Heath and Chesterfield. The ice-front would by this time abut against the rising ground from Thrybergh to Conisbrough, and a narrow lake would be formed overflowing at Conisbrough Park into a channel at 260 feet above O.D., which leads into the gorge behind Conisbrough Castle. A slight further advance of the lobe of the first glacier through the gorge would close the Conisbrough Castle channel, and cause the lake to overflow at 260 feet into a channel leading straight to Balby (Fig. 9), which was then a little valley carrying off the drainage from the high ground about Edlington. For a time there would probably be a considerable stream of clear water flowing from this lake over Magnesian Limestone and through the Balby valley, which would sweep clean the sandstone bed of the valley (Plate LIX., Fig. 2) before it was invaded by the second or Stainmoor glacier, which would catch up and carry forward much of the Coal Measure and Magnesian Limestone material left by the lobe of the Pennine glacier. Another forward movement would bury the Balby valley, and the drainage from the lake would have to travel along the edge of the ice, and thus the Loversall valley was commenced (Fig. 9). This was cut sufficiently low to take the drainage from the Edlington area when the ice retreated, and so the stream which starts towards the Don makes a semi-circular bend, and, doubling back parallel to its previous course, flows into the Trent (Fig. 3). Continued advance of the second glacier to Edlington would almost close the outlet of the great lake, but there is a shallow dip at Edlington very plainly shown on the six-inch map, as it just cuts through the 300-foot contour and is at right angles to the neighbouring valleys, which may be the shallow channel cut along the ice-front just before the lake was closed (Fig. 9). When the ice-front reached Clifton (Pl. LXI.), the gorge would be entirely closed, and a lake thirty miles long would be formed, reaching from Clay Cross and Hardwick Hall on the south to Bretton Park on the north, and ramifying far into the tributary valleys of the Don and Rother. This lake would overflow by the Kiveton gorge into the River Ryton, and thence into the plain at Worksop.

The gradual advance of the ice up the southern slope of the Conisbrough gorge towards Clifton, with the continual flow of water along its front, would explain the remarkable recession of the Upper Magnesian Limestone on this side, as compared with the opposite side of the gorge. It also accounts for the curious triplet of valleys at Hemsworth, Balby, and Loversall (Figs. 3 and 9). The outlet at Kiveton and the consequent level of the great lake at 330 feet (Pl. LXI.) also coincides with the warp bands between the boulder-clays at Staincross, which lie just above the 300-foot contour (Pl. LIV.).

The second (Stainmoor) glacier is assumed to have advanced in this area until its front occupied a curve (Pl. LXI.) from Staincross to Ardsley, and thence to Adwick and Conisbrough,

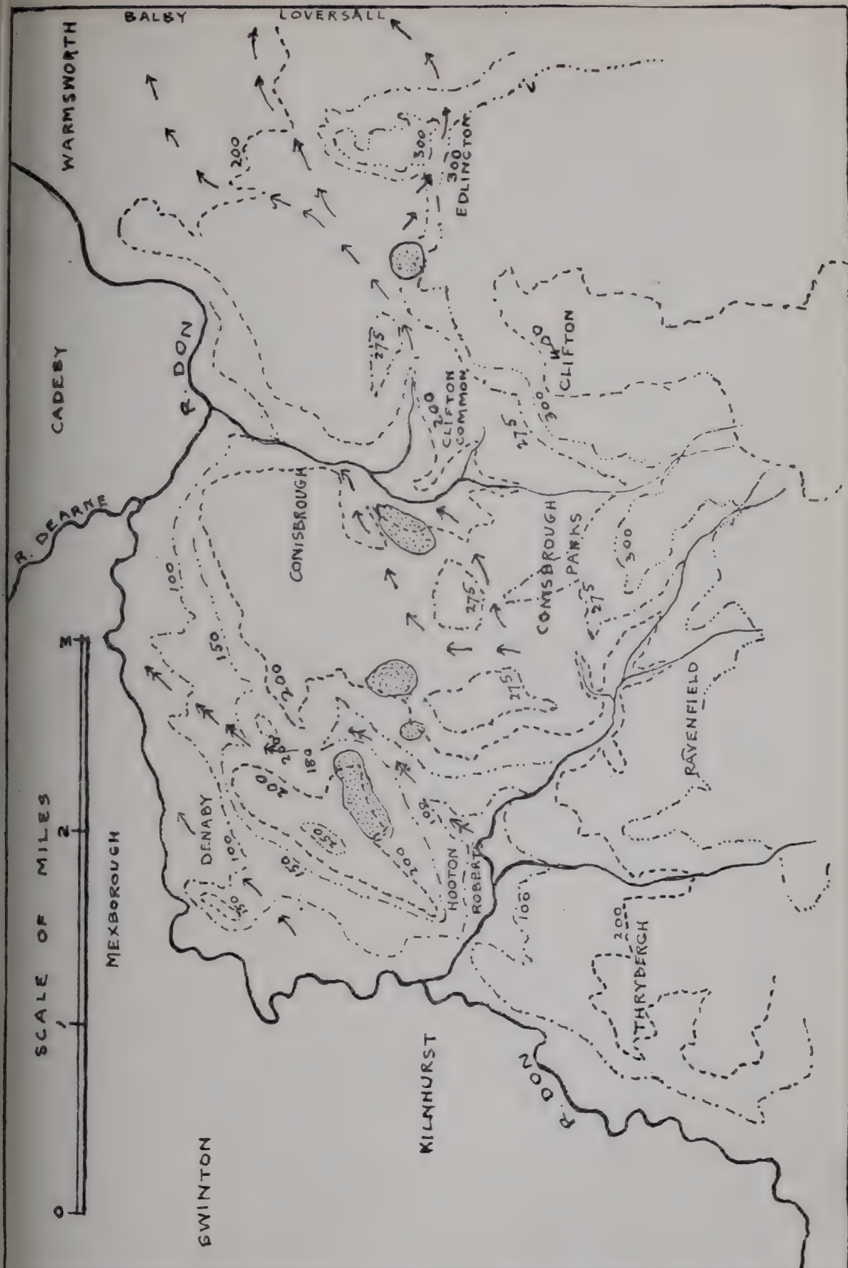


Fig. 9.

MAP OF THE CONISBROUGH DISTRICT.

The dotted areas are patches of drift. The double arrows show the suggested route of the Thrybergh stream before glacial diversion. The single arrows show the directions of overflow into the Don towards Balby, and towards Loversall.

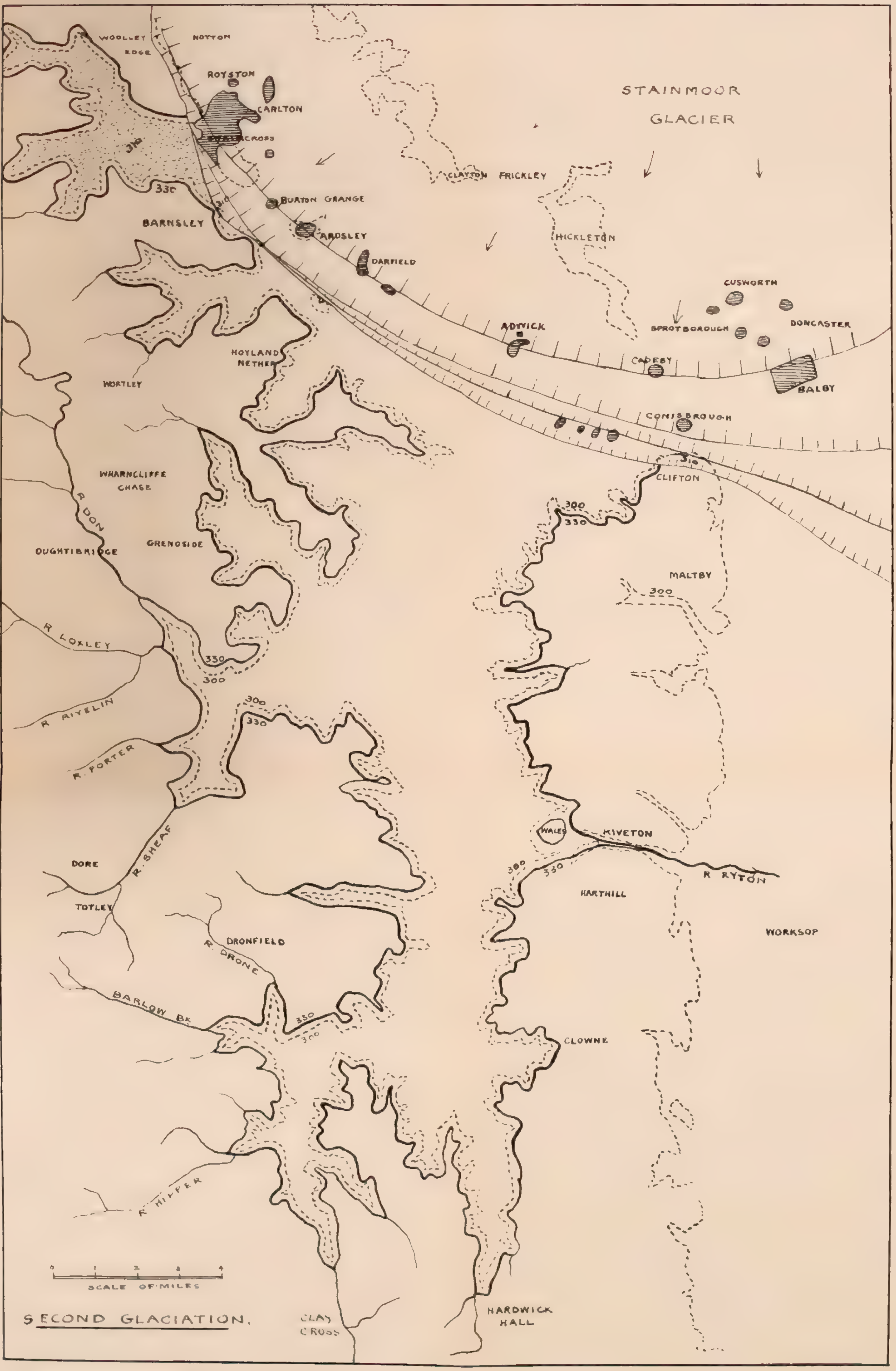
as there are none of its distinctive rocks found in any of the drift deposits to the south of this line in the valley of the Don. The scattered pieces of slate and jasper reported by Dr. Sorby in the valley of the Rother may be explained by the agency of icebergs from the lake-washed ice-front.

When the ice at Staincross pushed down into the valley of the Dearne at Barnsley, as indicated by the Old Mill section (Fig. 2), the valley would be completely blocked, and the lake formed would have no escape except by the little col under Harborough Hill, Barnsley, at 310 feet, through which the Lancashire and Yorkshire Railway now runs.

When the ice stood with its front at Adwick-on-Dearne, the overflow of the shallow lake in the valley of the Dove would be by a little valley at the 125-foot contour, between Mexborough and Wath, through which the railway and canal now go. At this period it is probable that the valley of the Don at Mexborough was blocked with ice, and the fine dry valley at Denaby excavated (Fig. 9). This valley is cut down from the 150- to the 100-foot contour, but the old river channel was already cut to a lower level, and so on the retreat of the ice the river resumed its old course.

There is also a little stream flowing northwards from Thrybergh which appears to owe its present course to glacial diversion (Fig. 9). At Hooton Roberts it faces a wide, drift-encumbered valley, but, turning at right angles, flows through a much narrower and newer gorge to the Don. The explanation offered is that the old valley of Hooton Roberts was choked at the Denaby end by an ice-barrier, and that the lake formed drained over into the Don and commenced the present drainage valley, which was cut below the level of the col of the Hooton Roberts deserted valley, which is at the 180-foot contour, before the disappearance of the glacier.

The logical result of all this ice movement is the entire closing of the Calder valley. We cannot stop the movement short of Woolley Edge ridge, on the eastward slope of which, up to 250 feet, are several drift gravel patches. A great lake would necessarily be formed in Calderdale, fed by the overflow from the Lancashire side by way of the Burnley and Summit valleys. This lake



Proc. Yorks. Geol. Soc., Vol. XV., Plate LXI.

MAP OF THE SUGGESTED ADVANCE OF THE STAINMOOR GLACIER UNTIL THE CONISBROUGH GORGE WAS CLOSED AND LAKE DON (330 FEET O.D.) WAS FORMED.

would gradually creep up to Mirfield, accounting for the great deposits of drift at 150 feet above O.D., with abundance of great angular blocks of ganister, and to Elland, where there are extensive detrital deposits in the valley, and up to Mytholmroyd, where it would account for the great delta from 330 to 360 feet above O.D.* The northern edge of this lake would creep up to and over the watershed of the Calder and Aire at Lofthouse and Rothwell, would discharge its waters over the gap at Tingley into the Churwell valley, and, lapping round Middleton, would be bounded northwards by the Airedale glacier.† This lake would thus serve to explain the Rothwell and Oulton sands and gravels which cap the watershed between the Aire and the Calder from the 175th to the 275th contour. These gravels are largely composed of Coal Measure material, but pebbles of Carboniferous Limestone, chert, and Silurian grit have also been found in fair numbers.‡ I regard these detrital deposits, often well bedded and associated with fine tenacious clays, as part of the lateral moraine of the Airedale glacier rearranged in the lake which washed the side of the glacier. The termination of the expansion of Lake Calder would be reached when it reached the level of the col between Crigglestone and West Bretton (405 feet above O.D.), when its waters would then be discharged into Lake Don, by way of which they would pass by the Kiveton gorge into the Triassic plain, which was then probably also a glacier lake.

The author does not contend that the evidence now adduced amounts to a demonstration, but the considerable number of facts brought forward appear to him when linked together to form a powerful chain of argument. When the re-survey of this area is undertaken by the Geological Survey, it is probable that many additional facts will be unearthed by which the results of this investigation will be tested. All that

* Law and Simpson, Report on the Drift Deposits of Mytholmroyd, Proc. Yorks. Geol. and Polytec. Soc., XIV., p. 231.

† Jowett and Muff, Glaciation of Bradford, &c., Proc. Yorks. Geol. and Polytec. Soc., XV., 245.

‡ E. Hawkesworth, Programme for the Leeds Meeting, Y.G. and P.S., March 2nd, 1905.

is claimed is that an attempt has been made to piece together a considerable number of obscure facts, and that in the operation considerable probability is obtained of the existence of the particular phase in the glacial history of England for which he contends, in the hope that the views set forth may be a help towards the solution of the many difficult glacial problems that still wait for solution.

*** The author desires to express his thanks to Messrs. Godfrey Bingley, W. E. Brady, C. Bradshaw, F.C.S., and R. A. Bellamy for kind permission to reproduce the photographs forming Plates LII., LV., LVI., LVII., LVIII., and LIX.

The Pleistocene Deposits of East Anglia.

Correction.

In Mr. F. W. Harmer's paper on "The Pleistocene Deposits of East Anglia," Vol. XV., p. 325, the second footnote on page 325 states that "as far as the district to the east of the Lincolnshire Wolds is concerned, the evidence," &c. Mr. Harmer writes to say that the word *east* should evidently have been *west*. The note will then read:—"As far as the district to the west of the Lincolnshire Wolds is concerned, the evidence shows that the ice moved from north to south, and not northwards from the Fens."

OUR COAL RESOURCES.

BY WALTER ROWLEY, M.INST.C.E., F.S.A., F.G.S.

(*A presidential address delivered before the Yorkshire Geological and Polytechnic Society, February 25th,* 1904.)

It is now some 33 years ago since, in the year 1871, with the confidence of youth I ventured first to address the members of this society at Doncaster, my subject being "Some Observations on Coal and Coal Mining, and the Economical Working of our Coalfields," and therefore it will, I think, not be without interest to glance at the tremendous strides made in the science and art of mining in recent years. In the year 1870, the production of coal from the collieries of Great Britain was 110 million tons, while the output of 1903 was, roughly, 230 million tons, or more than double; but while the output has doubled, the death rate from accidents has been very greatly reduced, from 1 in 345 of persons employed in 1870, to 1 in 805 in 1902. This remarkable decrease in the number of accidents is undoubtedly due to the rise of greatly improved means of education, which led to the passing of the various Coal Mines Regulation Acts, and the appointment of inspectors of mines. The question of our coal supplies and their duration has been often discussed, and the last Royal Commission on the subject was held in the year 1870. It is an interesting and fascinating subject, the importance of which it would be difficult to overestimate; the difference in prosperity between a country richly endowed with coal and one without, being strikingly borne out by the case of our sister isle Ireland, whose great floor of Carboniferous Limestone and small patches of Coal Measures point to the probability that it was at one time covered with Coal Measures, which, unfortunately, have been denuded away. It is, therefore, very gratifying to those of us who have long given the subject anxious thought, to see springing up this universal desire on the part of all to conserve the resources which have been so generously bestowed, for, in this country, the proportion between our coalfields and the area of land is

1 to 12, that is to say, our coalfields form one-twelfth of the area of the country, a proportion far exceeding that of any other country in the world. In dealing with our available resources one of the great factors to take into consideration is the depth at which coal will be able to be worked, and on this point a great deal of valuable evidence has been published by the Coal Commission now sitting. The deepest coal workings in the country are those of Pendleton, near Manchester, at 3,483 feet deep, where the temperature of the rocks has been measured at 100° F., with a temperature in the roads of 87°, and before our deepest coal seams can be worked science will have to come to our aid with some practical and still economical way of cooling down the workings. There will be no engineering difficulty in winding the coal from these great depths—the limit is a question of increase in temperature only. Then with regard to the workable thickness of coal seams. The evidence already given shows us that seams of coal 10 inches in thickness are being worked in some parts of the country, while seams of 12 inches to 18 inches are so common as to excite little comment, so that in estimating our resources all seams down to 1 foot in thickness may be considered practically workable. The most important point in regard to our coal resources, in my opinion, is that of waste in working. It has been my lot to inspect the workings of many large collieries, and there is undoubtedly ample room for improvement as regards methods of working. At many large collieries it is the custom to bring out only a small proportion of the small coal, especially in Wales, but surely this waste should be a subject almost calling for Government interference. Then, again, in districts where the coal seams lie close together, it is a common thing to see one seam utterly spoilt in order that the best and most valuable may be worked first, and in these cases it is my opinion that the working of the seam should be abandoned, instead of working it to the serious detriment of the others, and that at a time when coal from other seams which are economically worked is plentiful. To geologists, no doubt, the question of our coal resources appeals chiefly from the point of view of our hidden resources, and in this respect no coalfield has such prospects as the Great Midland

coalfield, on which we are situated. The eastwardly development has been very great in recent years, perhaps the most striking feature being the proving of the Coal Measures at workable depths at South Carr, 10 miles south-east of Doncaster, where the Barnsley bed was found at a depth of about 1,000 yards with a thickness of over 8 feet, but divided into two parts by a parting of 36 feet of shale. This has considerably pushed forward the proved eastern boundary, and verifies my prophecy of 30 years ago that Doncaster would be at one time a most important centre of the Midland coalfield. It is interesting to note that the number of persons employed in the Midland coalfield reaches nearly a quarter of the total mining population of the United Kingdom. Not so fortunately situated are the coalfields of Northumberland and Durham, whose eastwardly limit is fixed by the distance it is possible to carry the workings under the sea, probably six or seven miles. In central and southern England, however, the conditions are not so thoroughly known, and coalfields still remain to be discovered, though the only method will be by costly diamond borings. Though opposed to grandmotherly legislation, I think this is a field of work which should be undertaken by the Government and not left to private enterprise, which moves too slowly in matters such as these, but, of course, the cost incurred should be borne where coal is found by the owners of the estates on which it is found—the payment to take the form of a charge on each ton of coal got from areas proved in this way. In France and other Continental countries tnis question has long been recognised as of national importance, and extensive boring operations have almost fully proved the extent of their coalfields. The time has now arrived when the possibility of coal being found at workable depths under the Secondary rocks of southern England should be settled in the way indicated. Economy in fuel consumption is another great field for missionary work. The last few years has seen the rise of the electric power companies designed to supply electricity over whole counties, and in these lies the great possibility of economy for industrial purposes, which, of course, arises from—(1) the centralising of the plant and the fact that there will be a constant load owing to the supply of electricity for power in the daytime and for light at night; (2) the use of the most approved steam-raising and using plant, or as an alternative the use of producer gas, which can be used most economically in gas engines; (3) the employment of the lowest grades of fuel, which are now either wasted or command a very low price. Another proposal, which is also being carried out with the sanction of Parliament, is the distribution of Mond gas for power purposes, and we have the South Staffordshire Mond Gas Company at present putting this project into application. These and similar schemes are bound to revolutionise the consumption of coal and effect very great economies, doing away with innumerable small and wasteful steam plants, and we may expect our annual coal production to soon reach its maximum and then drop, but the cause of the fall will not be due to the exhaustion of our coal supplies, but economy in its use whereby coal is made to go farther. In the last 30 years remarkable changes have taken place in the scientific aspect of mining. We have seen the substitution of fans for furnaces, the abandonment to a large extent of pillar-and-stall and other wasteful methods of working in favour of the long wall method, in which the coal is removed in one operation; we have seen also the discovery that coal dust is explosive under certain conditions, the abolition to a large extent of horse haulage over long distances in favour of the wire rope; the employment of high pressure steam generated in Lancashire boilers instead of the old egg-ended type, the application of mechanical means to the under-cutting of the coal; and in the increasing use of electricity we shall no doubt have further alterations taking place in the next 30 years. There is no doubt that the physical character of our collieries will change, and thick seam collieries become thin seam collieries. Increased attention will also have to be paid to steam-raising appliances so as to reduce the consumption of coal at the colliery to the minimum, and also to coal screening and coal-washing plants, to make the inferior seams equal to those that are being worked at present. In conclusion, I should like to refer briefly to a subject recently raised—namely, the nationalisation of our steam coal mines. The smokeless steam coal of South Wales is, of course, a limited amount, and the attention of the Government has been rightly called to the fact. The structure of the South Wales coalfield differs from that of the Midland coalfield in being entirely exposed; it practically forms a complete basin, so that the resources can almost be ascertained with exactitude—there are no concealed resources. There is not the slightest doubt that the subject is one that requires to be dealt with at once; the needs of the Navy are known, and the tonnage required for the next generation or two can be ascertained. Why not, then, bespeak the coal now while we have it? The solution to the difficulty seems to be in the Government securing the lease of the areas remaining yet to be worked and keeping them in reserve, not allowing them to become the property of private capitalists, who would require very much enhanced prices. The taking up of the remaining areas would go far to secure the future supplies of our naval coal. I cannot conclude without again urging how great is the importance of this matter to the nation, on account of our naval supplies, and also in case of need for the supply of that necessary adjunct—the merchant service. So far no substitute has been found, and, in my opinion, it is not likely that one will be found, and as the supply is comparatively limited, we must consider whether it is advisable to so liberally supply the navies of other countries with this valuable commodity.

* * * *

Since the above address was given, the Final Report of the Royal Commission on Coal Supplies has been published.

To briefly summarise the results obtained—

(1) The Commission have adopted as the limit of mining a depth of 4,000 feet.

(2) The minimum thickness which has been included in the estimates is 1 foot.

(3) The estimated coal resources of the proved coalfields not exceeding 4,000 feet in depth are given as 100,914,668,167 tons.

(4) The estimated coal resources of the concealed and unproved coalfields, at depths less than 4,000 feet, is 39,483,840,000 tons.

The report of the Geological Committee shows that the great coalfield on which we are situated contains concealed resources under the Permian, Trias, &c., very nearly double those of all the other concealed coalfields put together.

The South Yorkshire and South Nottinghamshire districts will very shortly be the scene of further important colliery developments.

The collieries sunk in the next few years will be very large ones, royalties being obtained now which were considered at one time large enough for two first-class collieries. Sinking operations have commenced at Bentley, near Doncaster, and are contemplated at Brodsworth, to the west of Bentley, and Askern on the north. At Frickley the Shafton coal has been struck at a depth of 239 yards, which will make the depth to the Barnsley seam here over 600 yards.

Borings are being put down at Barlow, near Selby, and at Thorne, both of which have reached Coal Measures, and the result of these borings will be watched with great interest, as giving information as to the commercially workable limit of the coalfield of Yorkshire.

At Oxton, about seven miles north-east of Nottingham, the Babbington Coal Co. are putting down a bore hole, which will have the effect, if successful, of extending the coalfield on the east of the Leen Valley line.

The south part of the Midland coalfield, however, has been rather disappointing, as proved by the borings at Edwalton and Ruddington.

NOTES ON GLACIAL DEPOSITS NEAR PICKERING.

BY J. T. SEWELL.

In Professor Kendall's paper on "The Glacier Lakes of Cleveland" (Yorkshire Geological and Polytechnic Society, 1903), mention is made of the delta formed at the mouth of the Newton Dale valley, and he describes how it was through this dale that the Cleveland drainage flowed into the then existing "Lake Pickering." Being in Pickering a short time ago, and hearing of some well-sinking in the neighbourhood, I thought an account of the spoil, as confirmatory of the above paper, would be of interest to your readers.

Well at Bever's Mill.—Situated half a mile due south of Pickering Railway Station; it is 15½ feet deep, and no solid rock was found; this well is sunk in the lowest part of the present surface drainage, and directly in line with the Newton Dale outflow. The spoil consisted of river gravel and small stones, all water-worn, amongst which were embedded round and rounded stones varying from 2 feet to 6 inches in diameter. There was no clay and no earth mould, while the smaller stones were flat with rounded edges; still there was a total absence of slabs of rock, such as are generally found in most of the local streams. These had evidently been broken up in their passage down the gorge by the more massive boulders into pieces 2 to 4 inches long.

We note the following:—

Local Oolitic Limestone; largely represented by coarse sand and small pieces of rounded stone.

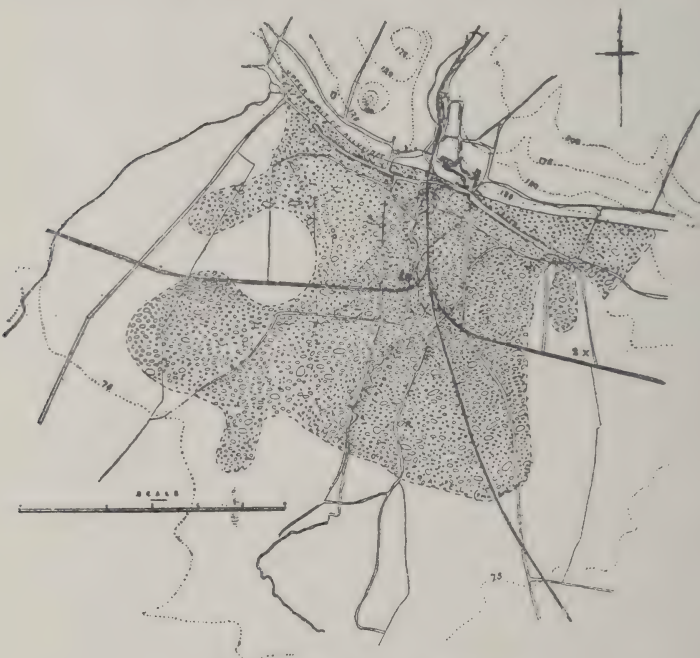
Kellaways rock in various sizes; one piece showed the casts of belemnites very little worn.

Limestone Marls. These hard rocks still retain their flat sides; the edges, however, are well rounded.

Coarse-grained sandstone, reddish. These boulders had the appearance of granite and were very hard, but the "shell" once broken were found to consist of a friable, grainy Estuarine series.

Whinstone. Two long rounded pieces noted, 8 or 10 inches by 4 inches. These were quite red, resembling the weathered rock at the edge of the dyke; the oxydised skin might be ⅛ of an inch thick. They broke with a black heart.

The most interesting find was, apparently, a rounded piece of dirty umber-coloured clay (18 inches by 10 inches). It had probably been lifted by hand out of the well, so may have been harder before being exposed to the air. Upon driving the hammer-



MAP OF THE PICKERING DELTA.

head into it I noticed that a piece came away with a clean break, and on breaking it further found that the centre still showed the close black laminated layers of either the Lias or Oolitic shale.

Many other rocks not known to the writer, except as local types, were heaped together at the well mouth.

Well No. 2 was situated about half a mile east of the one just mentioned and south-east from Pickering Station, showing on the chart just outside the east edge of the "delta." It was only some eight feet deep, and intended to store the roof water of two cottages.

The sand excavated was very earthy; many fairly large water-worn boulders, but as far as could be seen all were local limestones. The surface of the well would probably be a few feet higher than "Bever's," hence the digging would hardly reach the "delta," if the latter existed so far to the east.

Midway between Bever's Mill and Pickering Station, a gang of men were laying a gas-main along a country lane leading towards the town. The excavation showed one continuous flooring of water-worn boulders, most of them being one to two feet in diameter; the men used crowbars to lever them, and lifted them out of the trench by hand. The foreman stated that he had seen no granite, and only one black hard rock (whinstone). I saw no rocks but of the Newton Dale formations; they were very closely bedded and with little earth or sand covering.

The "delta" must have been formed by a very different river from the stream now flowing through Newton Dale.

We must also remember that there is no Lias or whinstone on the south, or Pickering, side of the present watershed.

NOTES ON THE "OVERFLOW CHANNEL" IN NEWTON DALE BETWEEN LAKE WHEELDALE AND LAKE PICKERING.

BY J. T. SEWELL.

Probably we are all acquainted with Professor Kendall's work on "The Glacial Lakes of Cleveland," and many of us may have been stimulated to go over the ground, and to find out—he having given us the key—what we can about this Ice Period of North-east Yorkshire.

It is my hope to throw a little new light upon the carving of Newton Dale into its present shape, and in doing so to confirm Professor Kendall's description of this dale as a great southern outflow of the Cleveland drainage, with its intake at Fen Bogs, and its delta at Pickering. I only consider this, however, as one of the many early overflow channels southward, and not necessarily the first.

May we briefly recall what would be the climatic and topographical condition of the district during the time of which Professor Kendall writes? The cold caused by, or the cause of, this inroad of ice would maintain great quantities of snow, which in turn would be rapidly melted by the warmer winds of summer, the sun probably having the same effect as it has in the Arctic and Antarctic regions—that of hardening rather than of melting the snow.

It has yet to be proved, but. by the lie of shingle-drift in Glacial sands, there is much evidence that the prevalent, or stronger wind in later Glacial times, has been from the west (beach on east side of lake).

We may expect that the Glacial lakes had a great variation in level, due to what we may speak of as winter and summer conditions; I doubt if this phase of the subject has had the study it deserves.

The surface, denuded of vegetation, or only clothed with an Arctic flora, would offer very little resistance to the rushes of water consequent on melting snow; also the porous Kellaways rock, and the sandy Estuarine series of the Middle Oolite, which form the outcrop over a great extent of the moors, would soon succumb to the alternating action of frost and water, and would rapidly become, may I say, rotten. We have Rotten Gill, the name of a place near Goathland, as a present day description of this condition.*

Those who have had the pleasure of reading Dr. Sven Hedin's account of the lakes and valleys of Northern Tibet, and his journey among them, will probably have a very correct description of the appearance and condition of the Jurassic ground surface when under the influence of the Norway ice. I do not speak now of what happened after the ice left, nor to the land under the ice-sheet, but of these soft series of shales, sands, and clays exposed to a climate which we may reasonably expect as correlative with the Ice Age.

From data already established we are, I think, safe in concluding that the land sank as the Ice Age progressed. Possibly the sinking took place immediately before, but as I understand boulders are found on the bed of the filled-up old river valleys—without a depth of sand or earth, in layers, between the bottom and the boulders—it appears that the land sinking and the ice advance were at the same time. Later it rose to much above its present level; this variation may have been as much as 200 feet. Since then it has again sunk in quite recent times. My strong opinion is that we have only to deal with one Ice Age, although its severity would wax and wane.

Course of the Stream. Flowing through Wheeldale Gill.

This present branch of the Murk Esk rises on land about 1,000 feet O.D. and flows through a valley bordered on either side by the 900 feet contour lines. Cooper Reed, in his "History of the Rivers of Yorkshire," gives a great importance to this stream, which he considers as a very old-time river. In this he is probably right, although its subsequent outflow into the Vale of Pickering through Forge Valley is, under the light of Professor

* The Oxford clay would probably at this time cover a large extent of the higher Kellaways strata. A line of outliers of this series still exist on the moors. This clay would weather even more rapidly than the Kellaways formation.

Kendall's later researches, hardly so likely to be correct. Nevertheless, I think it has flowed into Lake Pickering, though not near Seamer. In common with all the other streams flowing southward from the watershed, it would also in its earlier life have, in all probability, a directly south or south-eastern course, and not as at present form a tributary of the River Esk, which has a distinctly east and north flow.

Lake Wheeldale.

It is impossible to state the dimensions and exact position of this Glacier lake (Kendall), but in pre-Glacial times the outflow of a similar lake, or of a river (Wheeldale Gill Stream), was through the wide true river valley lying between Brown How and Wardell Rigg.* This valley, now partially filled up with peat, is called Slavey Slack, or Water Peel, and seems to have discharged its waters into a lake or river course in the region of Raindale, from which it continued to flow in a south direction through the southern end of Newton Dale to Pickering. This dale during the pre-Glacial time would not be cut down to its present low level; indeed, the Glacial overflow channel has been formed through what we may call the "Raindale Lake" bottom, as may be distinctly seen from the hills above Levisham Station. The Pickering end of Newton Dale appears to correspond in the direction and character of its drainage with Bilsdale and Farndale further to the west. The head waters of this pre-Glacial Newton Dale stream would be probably, as already stated, far to the north in Wheeldale Gill.

At what time, what is now the Murk Esk, captured the Wheeldale stream we cannot tell, but I very much doubt the existence of any pre-Glacial river course lying buried under boulder-clay between Hunt House and Goathland.

Having now considered Newton Dale south of Raindale, we must turn to Newton Dale north of Raindale. Until the break up of the Ice Age, which Mr. Kendall so ably describes,

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* The 800/825 contour stretches from above (south of) Moss Slack to south of Simon How (825) and, except for the cutting down by Blawath Beck, continues to Wardell Rigg.

I think we are safe in believing that the three more northerly miles of the five miles of Newton Dale, between Fen Bogs and Raindale, did not exist as a continued depression, unless that into each dale—Eskdale to the north, and Newton Dale to the south—flowed the drainage stream from Lilla Cross and Saltersgate respectively.

If this is so, the 800, or at that time possibly 900-foot contour line would be unbroken eastward from Wardell Rigg to the neighbourhood of Saltersgate.

Mr. Kendall shows how at one period during the Ice Age the ice pressing upon the land caused the drainage to flow due south, as already stated, he using Newton Dale as an example of one of these early overflow channels. My contention is that before the 800 feet contour line of Newton Dale was pierced, the "Lake Eskdale," flowing into the "Lake Wheeldale," had its waters held up to such an extent by the ice-sheet covering Eskdaleside and Goathland, that its overflow would be through the old river valley already described, and now known as Slavey Slack (820 feet O.D.), between Brown How and Wardell Rigg. This discharged into a lake covering the district around Raindale, the surface of which must have been above the 700-foot contour. The floor of this lake would correspond with the present Stony Moor (585-600 feet), which in all probability is now covered with the débris that has been carried by this early Glacial river. I have found a large boulder of whinstone, and ice-worn Kellaways rock similar to those that strew the old Hunt House and Goathland valley, above the 700-foot contour line to the south of Wardell Rigg. The peat-filled channel in Slavey Slack dies out after a drop of about 100 feet from the intake, which may possibly be choked with 20 feet of peat and sand.* If Slavey Slack is the highest overflow channel, then the ice in Eskdale† must have stood above the 800 feet limit, or at the same height as Professor Kendall finds it attained in the Scugdale area to the north, and

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* No water now flowing through Slavey Slack.

† *Eskdale* comprises the valley connecting Whitby and Goathland, and must not be confounded with the "Lake Eskdale" of Kendall! The latter is located as lying above the higher reaches of the River Esk to the North.

on Peak Hills to the south.* Again, the land must have been submerged to a great depth in the Pickering valley to allow of a lake with a water-line standing from the 700- to the 750-foot contour south of Wardell Rigg. May not this submersion account for the shaping of the tabular range of hills?

On the moor immediately south of Slavey Slack we note the following:—

(*a*) Large deposit of gravel near the edge of Raindale, directly south of Slavey Slack, although on much the same level as the moor surrounding (650). This gravelly land is cultivated.

(*b*) Large deposit of sand between the gravel and Slavey Slack.

In connection with the water level, I may mention a beach or terrace found (and I believe the only one in the district) at, as far as I can trace, between the 750–775 contour; it runs due north from Wardell Rigg along the western slope of the land, which would border to the east the post-Glacial "Wheeldale Lake," and must have formed its shore for some considerable time, and, unless the sill of Slavey Slack is hidden under many feet of peat, bringing it down to this level, we may believe that "Lake Wheeldale" drained into and through Newton Dale at the level of this beach for a very considerable time, the torrential rushes and overflow lake-bursts being at a minimum, while the ice-pressure on the land was at its maximum.†

As the ice receded the power of the melting water would be very much increased, and it would not take many years to cut down the 250 feet to the sill level at Fen Bogs. No data are,

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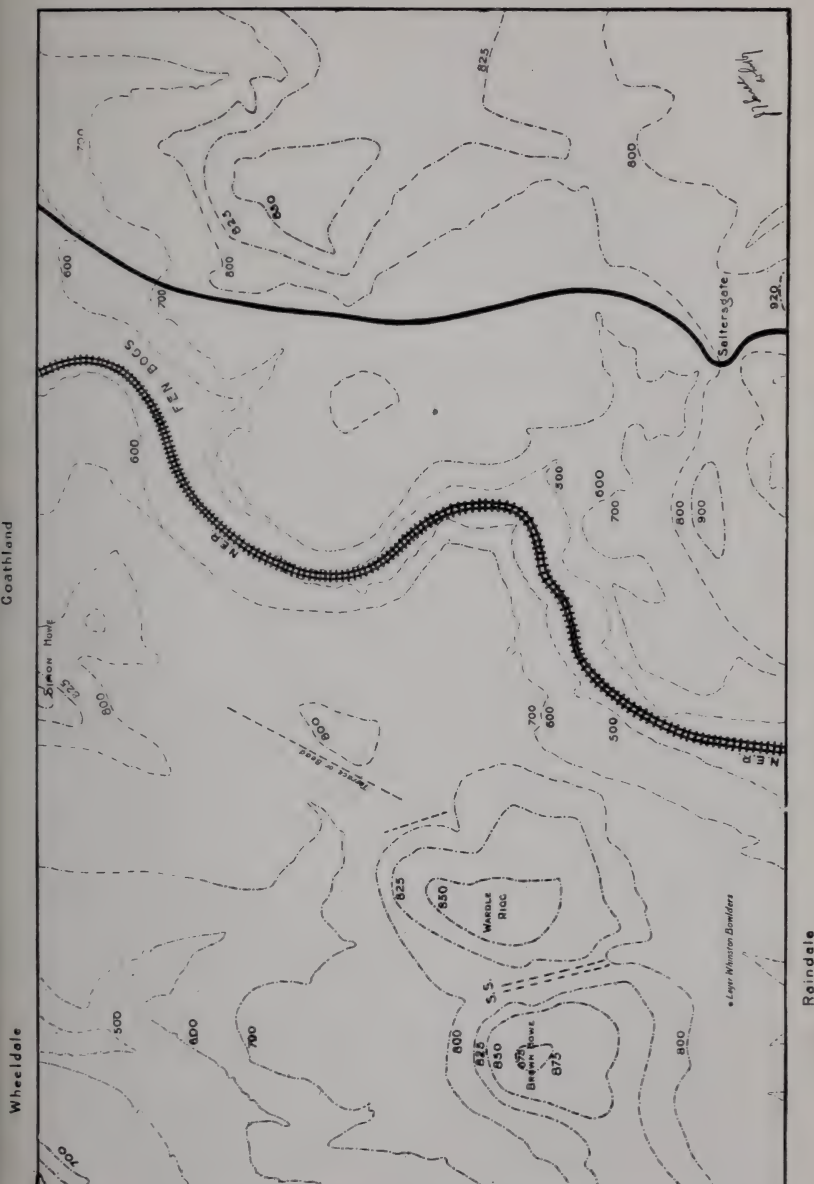
* I have traced a large Shap boulder above the 800-foot contour lying near the Whinstone quarries at Goathland. Kendall's Lockwood Hills, 867 feet; Basley Wood, 800 feet. Barrow says, "Drift disappears above 850 feet."

† I think it possible that the level of "Lake Wheeldale" rose at the date of its greatest extension to at least 900 feet O.D., overflowing into Raindale Head through Slavey Slack, and probably near Stape also; flooding the moors to the east it would pour down into the Saltersgate drainage at the north end of Newton Dale, thus preparing the gorge which the ice drainage afterwards took advantage of. This might possibly only occur when the summer melting of snow took place, and while the regular outlets were still blocked with winter ice.



MAP OF NEWTON DALE SOUTH OF FEN BOGS.

however, found by which we can gauge the dimensions of "Lake Wheeldale" between this and the shore-line cut in the Kellaways rocks as already described, until we come to Moss Slack, when we note the latest level of its intake to have been 675 feet above O.D.

The unrestrained mass of water discharging through and over the soft sandy Estuarine series would quickly wear away the five miles of river course between Fen Bogs and Raindale Beck, depositing its spoil as the delta in Lake Pickering.

To summarise, we are able to locate four distinct periods :—

(*a*) Ice drainage at 825 feet, and possibly up to 900 feet, steady and gradual, ice increasing or at its maximum, temperature at its lowest.

(*b*) Lake shore at 775 feet, showing drainage at this level gradual and lasting some time, temperature higher. Ice receding, possibly period of the earliest Newton Dale overflow.

(*c*) Moss Slack, level 675 feet, showing signs of a continual river channel draining a largely increased area through a decreased "Lake Wheeldale," and discharging its waters into Newton Dale, as described by Professor Kendall.

(*d*) Professor Kendall's account of the latest southern drainage over Fen Bogs sill (525 feet). Ice rapidly receding; water-flow much more violent, especially immediately following the close of the period described as (*c*), Newton Dale being continuously eroded through its entire length down to its present level.

"The evidence of overflows prove that at the maximum extension of the ice, a lake was held up in Eskdale to an altitude of over 725 feet" (Kendall). Again, page 18, vol. XV., part I., of the Yorkshire Transactions, "Lake Wheeldale drained by Moss Slack at 675 feet." But Two Howes Rigg is just on the 800-foot contour, and the river draining through Newton Dale probably flowed between the ice and Two Howes Rigg (*over* the above Moss Slack) at a much higher altitude than 675 feet, see (*b*).

A POST-PERMIAN FAULT AT CUSWORTH, NEAR DONCASTER.

BY H. CULPIN.

The Permian rocks in the neighbourhood of Doncaster fall into three main divisions :—

(1) The Lower Limestone, on the west, distinguishable by the massive character of the rock. Its bottom beds are fossiliferous.

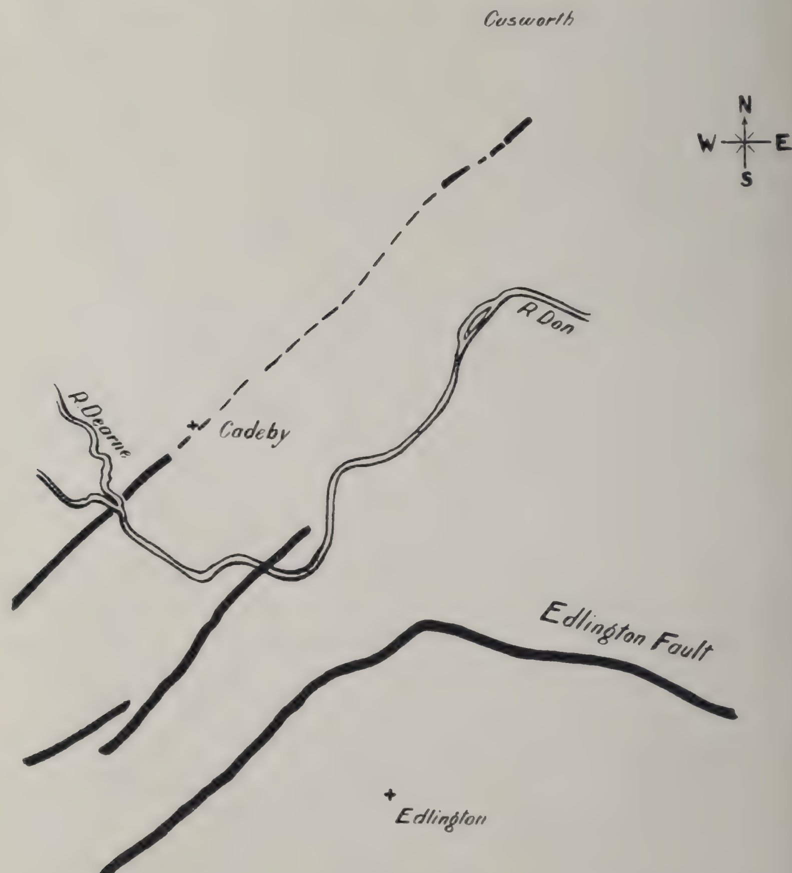
(2) The intermediate marls with gypsum.

(3) The Upper or laminated Limestone, on the east, with strongly marked bedding planes, and with fossils in the topmost layers.

In addition to the Don gorge, which is the principal and most imposing physical feature of the district, there are many small transverse valleys which take their rise in the Lower Limestone and then run eastwards, tapping longitudinal valleys in the marls. Several of these valleys are very charming, and one of the most attractive among them is that which commences about a mile north of the Sprotborough section of the Don gorge, and finally enters Cusworth Park.

Exposures of rock on the northern slopes of this valley (Plate LXII., Fig. 1) show the Lower or massive Limestone in close contact at the same level with the Upper or laminated Limestone, and indicate an important fault not yet marked on the geological map. This occurs below a mound described on the ordnance map as the supposed site of a castle.

The fault runs from south-west to north-east, and its hade is normal. The up-lift of the Lower or massive Limestone is on the north-west side, being the farther side from the Don. In the Edlington fault, about a mile beyond the opposite bank of the Don, the uplift of the Lower or massive Limestone is on the south, being again on the farther side from the river. These two faults, therefore, form a trough, in which lies the Don gorge. At their inception, the uplifted strata probably towered at a great height above the intervening surface, thus forming a deep wide valley, out of which the Don gorge has been subsequently scooped. On the Edlington side, the bottom, or fossiliferous, beds of the Lower Limestone overlook Upper Limestone strata still covered here and there with patches of Triassic sand. On the Cusworth side, the fossil-bearing beds are not exposed.



The Cusworth fault is a continuation in post-Permian times of the northern of the two faults marked on the geological map as terminating in the Coal Measures near the junction of the rivers Don and Dearne, below the Cadeby escarpment. This is confirmed by a cutting on the South Yorkshire Junction Railway

Photographed by G. Grace, Doncaster.

Fig. 1.

N.N.E. ASPECT.

Photographed by G. Grace, Doncaster.

Fig. 2.

S.S.W. ASPECT.

THE CUSWORTH FAULT.

about half a mile from the Cusworth exposure, in a direct line with the northern fault at Cadeby. The contours of the district between Cadeby and the cutting also support this view. The cutting (Plate LXII., Fig. 2) gives a fine section of the fault. There is a slickensided face of massive Limestone on the north, and the beds of the laminated Limestone curve slightly upwards towards the fault. Some 20 yards south of the fault, the laminated Limestone is fairly level.

The positions of the fault, as observed near Cusworth, are marked on the above map, and are connected by a dotted line with the northern fault at Cadeby.

SOME DRIFT DEPOSITS NEAR LEEDS.

BY EDWIN HAWKESWORTH.

On Sheet 78 of the Geological Survey one-inch map, between the rivers Aire and Calder, which unite about five miles to the south-east, are two patches indexed as "gravel, third river terrace." The northerly one, which may be termed, conveniently, the Rothwell Haigh patch, is roughly semi-circular in shape, and is separated from the southerly, or Oulton patch, which is of deltaic form, by a well-defined wide valley, through which flows the Oulton Beck. The size of the valley seems quite disproportionate to that of the present stream. The area of each patch is about a square mile, and their elevation varies from about 150 feet to 275 feet above O.D., but is mostly above 200 feet. The Aire near here is about 50 feet and the Calder about 60 feet above O.D. The solid rocks of the area belong to the Middle Coal Measures, the Thornhill Rock, a thick sandstone, forming a prominent feature on the southern side of the Aire valley. The recent deposits are so variable in character, even in a short distance, as the following particulars will show, that it practically is impossible to give measured and detailed sections.

Previous Observations.

These deposits seem to have excited little attention from local geologists. The only available mention appears to be by the members of the Geological Survey.* It is only brief, and, after mentioning their position and elevation, it states "the probability seems to be that they are river gravels of considerable antiquity, formed when the river was flowing at the level on which they lie." Only one section was seen, and that in the Oulton patch, the contents of which were about 90 per cent. Coal Measure sandstones, with angular fragments of black or banded encrinital chert plentiful, also some large blocks and a few pebbles of Millstone Grit, and some angular and half-rounded blocks of calliard.

* Geol. Survey Mem. Yorkshire Coalfield, 1878, p. 783.

Messrs. Jowett and Muff* mention yellow boulder-clay, 10 feet thick, with boulders of ganister, encrinital chert, and striated Millstone Grit, at Rothwell Haigh. Mr. Muff informed the writer this was exposed in making drains, and its relationship to the gravels was not noted.

Present Sections.

Rothwell Haigh patch.—Near the westerly edge an excavation was made in 1904 for a storage reservoir, above the 250-foot contour-line (see A on map). It exposed about 10 feet of varying sand and gravel, of yellowish colour, with intercalated beds of large stones, current-bedded in places, with traces of contortion in one place. Towards the upper part, especially at the northern end, the material became more clayey. Rock was not reached here, but other temporary excavations in the neighbourhood prove a thickness of quite 30 feet of similar material.

About 150 yards south-east of the previous section (see B on map) is a sandpit showing from 10 to 15 feet of yellowish sand and gravel, but the number and size of the contained stones is not so large as at the reservoir, though they are so plentiful that all the sand has to be screened. To show the extreme variability of these deposits, this pit is now being worked in a westerly direction, exposing the following section :—

Very coarse gravel	2–3 feet
Sand, evenly bedded, practically free from stones	about 10 feet
Gravel	,, 1 foot
Large boulders resting on rock ..	,, 1 foot

In the sand are distinct incursions of rough, clean, angular white quartz grains, reminding one of broken-up coarse Millstone Grit, evidently not water transported for any considerable distance or time.

The finest and most interesting section in this patch is found in a large sand pit nearly opposite the John o' Gaunt Inn,

* A. Jowett, M.Sc., and H. Brantwood Muff, B.A., F.G.S., "The Glaciation of Bradford, &c.," Proc. Yorks. Geol. and Polytec. Soc., Vol. xv., Part ii., p. 219, 1904.

and between the 200 and 225 feet contours. (see C on map). At present it shows :—

Very coarse gravel or shingle ..	2–3 feet
Sand	about 15 feet
Very coarse gravel	10–12 feet
Sand	about 1 foot
Rough gravel, with large boulders, thickness not known.	

It may be possible before very long to obtain a view of the whole thickness of the deposit, and the character of the rock floor upon which it is laid. A few lenticular masses of clay occur in the sand, at times, but, at the south end of the pit, resting on rough gravel, a large mass of very fine stiff reddish clay was found, 2–3 feet thick in places. It was quite free from grains or pebbles of harder rock, and much of it was carted away for the purpose of puddling the adjacent reservoir. Above the clay was more coarse gravel.

About 300 yards east of the above section, the E. & W.Y.U. railway runs for some distance in a deep cutting through sandstone (Thornhill Rock). (See D on map.) This is overlaid by 10–20 feet of sands and gravels, which, though not very accessible, and now somewhat obscured, seem to be quite as variable in texture as in the other sections. They rest apparently on a flat surface of the sandstone, and it can be seen clearly how they cap the ridge dividing the Aire and Rothwell valleys. Running south, across the head of a small valley or depression, the railway cuts through a smaller thickness of the gravels.

Oulton patch.—Crossing the Rothwell valley, and passing through the ancient village of that name, the northern extremity of the Oulton patch is seen making a prominent feature in the landscape (Gravel Pit Wood, but no exposure now). About three-quarters of a mile south, near Royds Green, it attains its greatest elevation, 275 feet, this contour being formed roughly by a terrace-like spread of gravel. From here the ground gradually slopes away to the Calder valley.

So far as can be ascertained, the only section now visible is in a gravel pit near the Home Farm, Oulton, just above the

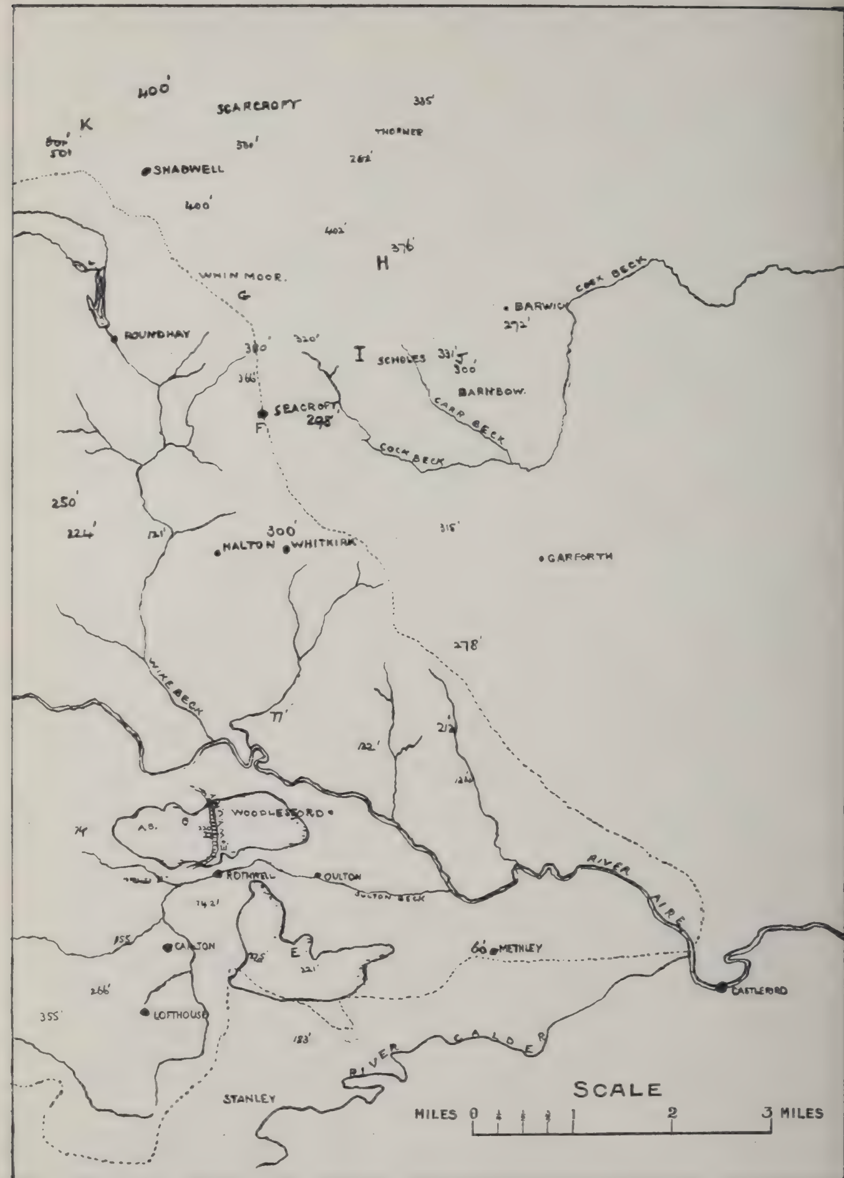
200-foot contour (see E on map). It exposes quite 20 feet of coarse sandy gravel, without reaching solid rock. It is very full of pebbles and stones of all sizes, some pieces of sandstone being as much as 2 feet square, and quite angular. There is little evidence of bedding or arrangement, the stones, large and small, being scattered most irregularly throughout the mass. In the north-west corner the deposit becomes more sandy, with coaley bands, fewer stones, and is more clearly current-bedded.

The Contained Stones.

With one or two exceptions, which further investigation may eliminate, both patches yield similar pebbles or boulders. The great majority are Coal Measure rocks—grits, sandstones, ganisters, and ironstone nodules. Millstone Grits and large quartz pebbles, probably derived from them, are present. There is a great number and variety of cherts, mostly in small squarish pieces, but with the angles sufficiently rounded off to indicate, in such a hard substance, that they have undergone considerable knocking about. Carboniferous Limestones are less common, leading one to infer that many of these must have been completely destroyed in the course of their journey from the source of origin. A fine piece of *Syringopora*, with the matrix entirely dissolved out, was found in the John o'Gaunt section, from which also were taken a number of small, very hard, and remarkably smooth rounded pebbles of fine grained crystalline, Carboniferous (?) Limestone, of quite a distinct character from any which have yet been noticed in the other sections. A few Silurian or Ordovician rocks have been found in both patches, but mostly at Oulton. No distinctly igneous rocks have been found, but one or two doubtful ones, one perhaps a quartz-porphyry, are awaiting microscopic examination.

Other Deposits to the Northward, between Aire and Wharfe.

Seacroft.—In making a manhole in connection with a sewer in 1904, about 250 feet above O.D., rounded boulders of ganister and sandstone were brought out (see F on map).



SKETCH MAP OF COUNTRY TO THE EAST OF LEEDS.

The gravel patches are outlined. The dotted line shows the boundary of the Aire watershed.

Whinmoor (see G on map).—The Geological Survey noted that over the country to the north of Leeds, great masses of drift occur, consisting mainly of stiff blue clay, containing amongst others mentioned, trap, flesh-coloured granite, and chalk. A bore hole at Whinmoor went through 114 feet of this stoney clay.*

Scholes.—Near here, in the cutting of the Leeds and Wetherby railway, between Scholes and Thorner, at over 350 feet above O.D., is a section of drift, in which have been noted, amongst others, cherts and grits.

At about same elevation, in Scholes, rounded boulders of very fine hard whitish sandstone were found in digging for foundations of a house (see I on map).

Cock and Carr Becks.—In many parts of these valleys, and adjacent, pebbles of sandstone, grit, ganister, and chert are abundant.

In other parts of this district traces of drift have been noted, as, for instance, in the fields north of Barnbow, about 300 feet above O.D. (see J on map), which are sprinkled with rounded pebbles of chert, sandstone, and ganister. At a higher elevation still, west of Scarcroft (see K on map), in making pipe trenches similar pebbles, with limestone in addition, were found.

Conclusion.

With the present available information, the writer is indisposed to generalise upon these observations, which are very detached, and somewhat obscure in some cases. The occurrence of real boulder-clay at Whinmoor and Rothwell Haigh seems to require further elucidation; especially does the presence of igneous rocks at the former locality.

It seems fairly certain that the Oulton and Rothwell Haigh deposits are not "river gravels of considerable antiquity," but these, taken in conjunction with the dispersal of pebbles and boulders very similar to those contained in them, between the Aire and the Wharfe, denote a period when the country between the Wharfe and Calder (if not further north and south),

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*Geol. Surv. Mem. Yorks. Coalfield, 1878, p. 779.

at all events east of Leeds, was covered with ice, or water, or most likely both in turn. However, the observations are now recorded, in the hope that in the near future they will be added to, and fit in with those of other workers in adjacent areas, thus making a complete chain of evidence, from which another chapter in the recent geological history of our county can be written.

EXPERIMENTAL PETROLOGY.

BY COSMO JOHNS, M.I.MECH.E., F.G.S.

(*Paper read at the Annual Meeting of the Yorkshire Geological Society, Wakefield, November 2nd,* 1905, *and since revised.*)

No one who has contrasted the wonderful progress made in the investigation of slags and alloys during the last ten years with the present state of petrological research after nearly half a century of patient work, can fail to recognise that the methods of metallurgists must, in some way or other, have been directed along more effective lines. That this has been practically admitted by petrologists may be seen by a reference to recent geological literature.

What has occurred is that the metallurgist has pressed into his service every possible method of research. The main principles of physical chemistry formed the basis of his working hypothesis. The microscope aided him to study the structure of the substances he experimented with. By suitable thermal treatment he determined the particular structure to be developed. By delicate pyrometric measurement he could learn something of the evolution or absorption of heat consequent on the structural changes that were taking place during the heating or cooling of the mass. Chemical analyses and physical tests would be appealed to, and the result is seen in the brilliant results obtained as a result of the study of alloys—and in a lesser degree, slags—by an enthusiastic band of workers in this and other countries.

In petrology it can hardly be said that any real progress has been made since Dr. Sorby, of Sheffield, read his, now classic, paper on the application of microscopical methods to the identification of the mineral constitutents of rocks. With the exception of a few well-meaning attempts to discuss certain physico-chemical problems, petrology has remained a mere description of the microscopical features of the rocks. Its workers now find themselves in the position of having to admit that somehow they have persisted in a path that has led them nowhere in particular, and that they must retrace their steps if they are to accomplish what should and must be their real work, namely, to elucidate the life-history of the Igneous rocks.

It might not be entirely out of place to discuss briefly the things that we are really seeking to know something about. If possible it would be desirable to know the composition and constitution of the original magma which fed the intrusive and contemporaneous masses we are dealing with. Its temperature and pressure, and the variations in these that resulted after extrusion had taken place. The conditions that determine the growth of porphyritic crystals—those that determine both regional and local segregation have not been stated. The physico-chemical changes that take place in the consolidating mass as the various minerals separate out, and the particular conditions that govern these changes suggest a series of problems whose complexity and magnitude will only become apparent when their solution is attempted.

Merely stating the problems does not constitute, at least, not directly, any useful contribution to their solution. The first thing required is the adoption of a tentative theory, based on the little we know already, as a working hypothesis. In the study of slags and alloys this has been found in the theory of reciprocal solution. The cooling fused rock mass may be considered as a complex solution. Which is solute and which is solvent is not always clear. That solvent may become solute at a certain critical point in the thermal history of the cooling mass is sometimes very evident. Now reciprocal solution is a conception sufficiently elastic for the early days of research, even if it does not furnish the key that will unlock the casket that contains all the treasures we are seeking. But if the theory of reciprocal solution be adopted, then we must commence to determine the solubility curves of the various minerals in the constantly changing mother liquor of fused silicates from which they separate when the fused rock mass is consolidating.

The brilliant work of Vogt, confirming Teall's suggestion that micropegmatite is the eutectic mixture of felspar and quartz, together with more recent field evidence, establishes the reciprocal solution theory as applicable to petrological problems. The case of the minerals which, like magnetite, crystallise at a very early stage of consolidation, often requires different treatment. Here it is not a question of the substance in excess over the eutectic ratio separating out, but rather that limited solubility is the determining factor, the solvent being a complex fused silicate.

It might not be out of place to state in more detail what is meant by this theory of "reciprocal solution" which is now offered as a working hypothesis upon which to base experimental research. It assumes—until new data prove that it requires modification—that the igneous rocks have consolidated from a fused mass, which was originally a more or less homogeneous mixture of various substances, the silicates largely predominating, dissolved reciprocally in each other, and that in this mixture might be dissolved other minerals of limited solubility and occurring more sparingly. At a sufficiently high temperature these would probably form in any proportions a true solution, that is, a homogeneous mixture. The lowering of the temperature would at a certain point destroy equilibrium and cause the differentiation of the mass into distinct portions that would, if the mass were not too viscous, separate according to their specific gravities.

As the temperature fell the mineral constituents would separate out, not necessarily in the order of basicity or in the order of fusibility, but according to their solubility in the still unconsolidated, but progressively changing, mother liquor. If at any stage a eutectic mixture results—and this is not necessarily the final stage—its structure would depend upon the temperature gradient. If that were too rapid, an emulsified structure would result. If normal, then the usual eutectic system of parallel plates; or if the gradient were very flat the minerals might have time to separate even still more. Then it should be remembered that these transformations are reversible. If, say during intrusion or extrusion, the pressure sustained by the mass be reduced and sensible heat liberated, the temperature might rise sufficiently to cause any crystals already formed to enter, or commence to enter, into solution again. Even if the liberation of sensible heat were not enough to raise the temperature of the mass, it might be sufficient to maintain it stationary for a time, and thus cause structural modifications. Further, at any stage the mother liquor might arrive at a composition which would freeze as a solid solution or glass.

As a small contribution to the work, the results of certain experiments made recently by the present writer are offered, with the warning that the conclusions are but tentative and only to be adopted with caution. Silica and silicates may be looked upon as the chief solvents in igneous rocks. It is true that silica also, at some stage or another, appears as a solute and separates out in most of the igneous rocks, but that does not seriously affect the view that we are dealing with solutions of various minerals in fused silicates of a composition that varies as the consolidation of the rock mass progresses, and that the solubility of these minerals in any particular silicate is a function of temperature, except when it is capable of forming a solid solution. Silica would therefore appear to offer a promising line of attack.

A quantity of pure quartz sand was taken and exposed at a temperature exceeding 1,800° C. to an atmosphere containing much finely divided magnetic oxide of iron. The temperature was just sufficient to fuse the quartz, thus confirming Boudouard's determination that the fusion point of silica is 1,830° C. When the mass of quartz sand was withdrawn, it was found that the surface, to the depth of eight millimetres, had been fused, and that it was coated with magnetic oxide. The coating was a little less than one millimetre in thickness, but after cooling it could be easily removed with the finger nail. It was very evident that magnetic oxide is not soluble in fused silica. Further experiments were then made, during which silica was exposed at varying temperatures for a period extending over several weeks, to finely divided magnetic oxide. In no case was there any sign of solution, and it seems established that magnetic oxide is not soluble in silica between 200° C. and 1,830° C., which were the limits during the experiments.

Using a fused mass having the following composition as a solvent :—

SiO_2	53·68
FeO	20·04
Fe_2O_3	1·86
Al_2O_3	4·61
MnO	14·62
CaO	2·50
MgO	2·58
Total	99·89

with some CaO, it was found that silica was soluble in it in varying proportions at temperatures below that of the fusion point of silica itself. Magnetic oxide was soluble in the original silicate, and the surface film, so easily detached in the case of pure fused silica, was firmly adherent, and in the cold state could be seen to have diffused into the silicate mass for some distance. By adding silica in increasing quantities to the original silicate, and thus increasing its acidity, it was found that its power of dissolving magnetic oxide decreased. Solubility was therefore, at a temperature somewhat below 1,800° C., in the inverse ratio to the acidity.

As the opportunity offers the experiments will be continued, using other silicates as solvents and varying the temperature, and also using other minerals as solutes. So far as they go the results seem to point to the varying solvent power of fused silicates on small quantities of minerals, such as magnetite, zircon, &c., during a progressive fall of temperature, as being the factor that determines their early separation in acid rocks like granite.

In Memoriam.

WILLIAM ACKROYD, F.I.C., F.C.S.

Born March 3rd, 1852.

Died May 9th, 1905.

By the sudden death of William Ackroyd the Yorkshire Geological Society has lost a devoted scientific worker, and our Council one of its most genial and energetic members. Though devoted to his own particular branches of science, chemistry and physics, he found so many interesting avenues of research opening out in this direction and that through the goodly realm of geology, that he became more enthusiastic than many geologists in pursuing lines of special investigation which threw additional light on many important earth problems.

From a boy he showed an aptitude for science, and his love for chemistry and physics began early. On leaving school he entered as a student at the Royal School of Science, South Kensington, where he remained for five years, pursuing his studies with true scientific enthusiasm. On his return to Sowerby Bridge, his native town, he commenced business as a chemist and analyst. Subsequently he removed to Halifax, where he opened a laboratory as a consulting analyst, and became teacher of chemistry at the Higher Board School. On the opening of the Technical School he became head of the chemistry department. In March, 1886, he was appointed Borough Analyst for Halifax, which position he held up to the time of his death. In addition to his professional duties he ever kept a mind open to the advance of scientific knowledge, and pursued new lines of thought and research from time to time with a careful grasp of the essential facts, united with a bold and vigorous imaginative theorising.

As a Fellow of the Physical Society, the Chemical Society, and the Institute of Chemistry, he wrote and published many papers which expressed his views in an original and suggestive manner, and his presence at the British Association Meetings from year to year was not only a keen personal delight to himself, but was

Proc. Yorks. Geol. Soc., Vol. XV., Plate LXIII.

sure to be the occasion of welcome papers and remarks at his sectional meetings, and his loss will not only be keenly felt by local scientific workers, but in a far wider circle.

He took a keen interest in education, and combined marked capacity as a teacher with that warm personal interest in his students that made them regard him as their true friend. He took great pains in promoting the popularisation of science by lantern lectures and by attractive papers in magazines for the people.

Mr. Ackroyd was an active member of the Halifax Scientific Society, and was its first Honorary Secretary. He was also an ardent Freemason. Latterly he took a lively interest in the problems of colour in various chemical substances, and the discovery of radium, with the revolutionary problems to which its explanation gave rise, had a rare fascination for him, and it was with researches on the nature of this interesting and rare metal that he was most engrossed at the time of his death. He was a strong opponent of the electron theory.

When the Yorkshire Geological and Polytechnic Society commenced the work of exploring the underground waters of Malham, Mr. Ackroyd became a member of the Chemists' Committee and took a prominent part in the preliminary discussions. The consideration of the chemical tests to be used and the methods to be adopted was of great importance, as the investigation was in the nature of pioneer work, and the previous futile attempts to solve the mystery of the sources of the Aire made the chemists doubly anxious to devise tests which, whilst being innocuous to the fish, could be used in sufficiently large quantities to be readily detected under conditions of considerable dilution, and each of which could be readily detected in the presence of the others. Their choice fell upon common salt, sulphate of ammonium, and fluorescein, and the results were eminently satisfactory and issued in a triumphant solution of the problems which were faced; and the experience gained proved of immense value in the subsequent investigations in the more complicated area of Ingleborough. Those, however, who took part in these early investigations will never forget the anxious anticipations with which the tons of testing material were carted to the moors above Malham, the patient watching at the springs, and the solemnities connected with the establishment of the central testing station at the Buck Hotel, where Mr. Ackroyd presided with impressive dignity over the array of pipettes and reagents by which the shoals of bottles from the springs were tested. And as the shades of evening lengthened the lengthening faces of the disappointed chemists, as no results appeared, will never be forgotten by the writer. Ackroyd was one of those who, through the tantalising twelve days before the tests came out, manfully struggled with hampers of bottles duly forwarded from Malham—and no one was gayer than he when the results which he embodied in his chlorine-curve diagram were slowly revealed. His unflagging industry was also manifested in the early Ingleborough investigations, when 1,200 tests were examined, most of them, I believe, by Mr. Ackroyd himself.

One of his colleagues in this investigation gives the following impression of Mr. Ackroyd's personality and work :—"Ackroyd was, in some respects, an ideal colleague to work with, as he never spared himself, and if an idea had to be worked out, his example, as evidenced by unremitting attention to the problem in hand, stimulated all those who worked with him to their best effort. His chemical work was always painstaking and accurate, and was accepted as such by his co-workers. Those who knew him intimately were aware that some of his theoretical deductions in physics did not command general assent, but even in this domain his experimental work was original, ingenious, and resourceful. As a colleague he was very accessible, and as one who worked very closely with him whilst the Malham researches were being conducted, I can say how exceedingly valuable his help was to the Society. Without such helpers conjoint work such as was successfully carried out at Malham and elsewhere would have been either delayed indefinitely or prevented altogether."

Professor Joly's attempt to calculate the age of the earth by a comparison of the salt carried down each year by rivers and that contained in the ocean, found a searching critic and vigorous opponent in Mr. Ackroyd. His attention had been drawn to the chlorine constituent in river water during the

Malham investigations, as in this case the factor was permanent though there was practically a complete absence of chlorine in the rocks from which the headwaters of the Aire derived their salts. He read papers before our Society and the Chemical Societies in exposition of his views of salt circulation, by which he showed that the bulk of the salt carried seawards by rivers was due to spray carried inland by storms, and therefore was no actual addition to the ocean store. In the subsequent discussion Mr. Ackroyd well maintained his position. He frequently attended our Council Meetings, and the breadth of his scientific interests, as well as his genial personality, rendered his presence always welcome. As President of the General Meeting held in Leeds, March 2nd, 1905, he took a keen interest in the discussion on earth movements which was then initiated. In the last letter received from him by the writer, Mr. Ackroyd thus expressed a wish to deal with some of the large issues raised :—" I have just been looking through the Classified Index you compiled in 1903, and see that Cosmical Geology has had a place in our Proceedings. When time permits I will give a paper to the Society on this section of its work. It will fill an evening some time when you are short of papers." Not many weeks afterwards came as a severe shock the sad news that in one brief hour he had swiftly passed the line that separates our present ignorance from the wider knowledge and freer activity of the spirit-life beyond.

W. LOWER CARTER.

Amongst the Papers of which he was the author were the following :—

Transverse Absorption of Light (*Chem. News*, 1877).

Selective Absorption (Phy. Soc., 1876).

Researches on Moorland Waters—I., Acidity (Chem. Soc., 1899).

Researches on Moorland Waters—II., on the Origin of the Combined Chlorine (Chem. Soc., 1901, vol. 79).

Halifax Waters (*Halifax Naturalist*, Feb., 1899).

Lead Poisoning—its Causes and Prevention (York. San. Inspec. Assoc.).

Salt Circulation and its Geographical Bearing (Brit. Assoc., 1901).

Absorption of Röntgen Rays.

Radium and its position in Nature (*19th Century*, May, 1903).

Experiments and Observations with Radium Compounds (Brit. Assoc., 1903).

Colour Changes effected by Radium Rays (Soc. Chem. Ind.).

On the Origin of Colour (*Chem. News*, 1893, vol. 67).

Colours of Iodides (Brit. Assoc., 1903).

Inverse Relation of Chlorine to Rainfall (Brit. Assoc., 1901).

Distribution of Chlorine in Yorkshire (Brit. Assoc., 1901).

Telluric Distribution of the Elements (Brit. Assoc.).

Various Papers on the Teaching of Chemistry and Research Work done by Students under his supervision at the Technical School.

"The Old Light and the New." The Chemistry of Colour and the New Photography (1896).

SECRETARY'S REPORT, 1904.

Another year of steady, successful effort has to be reported, and it is satisfactory to note that there is no falling off in the number of members or the value of the work accomplished.

The Spring General Meeting was held at Leeds on Thursday, February 25th, and with it was associated a morning Field Excursion to Meanwood, led by the Hon. Secretary. The interesting sections in the ganister beds were examined and a walk was taken through Meanwood Wood to view the gorge in the Millstone Grit at Weetwood. After lunch some of the members visited the Leeds Philosophical Hall to hear Mr. Crowther's lecture to the children of the Leeds elementary schools on "Wonders of Insect Life." At the General Meeting, held at the Church Institute, the chair was taken by Mr. Walter Rowley, F.S.A., F.G.S., who delivered an address on "The Science and Use of Mining." A lecture was then delivered by Mr. Arthur W. Rowe, M.S., M.B., F.G.S., of Margate, on "The White Chalk of Yorkshire," which was illustrated by a number of beautiful lantern slides. The lecture was followed by a discussion, and hearty votes of thanks to the Lecturer and the Chairman concluded the proceedings.

The second General Meeting was held at Sedbergh on Friday, May 27th, under the presidency of Mr. Arthur R. Dwerryhouse, M.Sc., F.G.S., and was associated with a series of interesting Field Excursions under the leadership of Mr. W. Robinson, of Sedbergh.

On Friday, May 27th, the party visited Castlehaw Gill, at Sedbergh, and examined the exposures of Coniston Grits overlaid unconformably by the Basement Conglomerate of the Carboniferous series. Thence the members drove to Hebblethwaite Hall, where the Basement Conglomerate was again in evidence. In Hebblethwaite Gill several faults were noted and many interesting sections of the junction of the Silurian beds and the overlying conglomerate were seen. The leader then took the party to Penny Farm Gill, where there is a fine section in the upturned beds of the Great Scar Limestone, which are uplifted vertically by a branch of the great Dent Fault. A walk along the steep slope of Nor Gill showed the upturned and broken limestones in fine sections. The western slopes of Baugh Fell were then traversed to Taithes Gill, where a remarkable series of exposures were examined, showing the Yoredale beds bent and faulted. The underlying beds of the Coniston Limestone series were penetrated by sills and dykes of mica-trap and felsite. A protracted rain storm prevented the ascent of Bluecaster to see the boss of diabase.

At the General Meeting, held at the White Hart Hotel, one member was elected. A resolution was passed expressing sincere sympathy with the Rev. John Hawell, M.A., F.G.S., in his severe illness, and earnest hope for his speedy recovery.

The President, Mr. Arthur R. Dwerryhouse, M.Sc., F.G.S., then gave an address on the "Geology of Sedbergh and District," during which Mr. A. H. Pawson, President of the Yorkshire Naturalists' Union, occupied the chair. The lecturer said that the district was naturally divided into three divisions :—1. East, Carboniferous Limestone and Yoredale beds, underlaid by Silurians, which were exposed in valley sections. 2. Central area, between the Dent Fault and a parallel fault, consisting of the Coniston grits and flags, with Carboniferous rocks lying on them unconformably. 3. Western, consisting of Kirkby Moor flags, with a mass of Carboniferous Conglomerate overlying them. The Dent Fault is one of a series of faults, continuing the great Pennine Fault, which had a pre- as well as a post-Carboniferous movement, and the same may be true of the Dent Fault. It is probable that there were further movements between Carboniferous and Permian times, and also during the Permian period, Professor P. F. Kendall having shown this by referring to the pebbles of the two beds of Brockram in the Vale of Eden. The lower Brockram contains Carboniferous Limestone pebbles, but none from the underlying beds, but in the upper Brockram there are pebbles of quartzite from the Basement Carboniferous beds, and of Borrowdale volcanic rocks. The Dent Fault is a thrust fault. The Silurians of Howgill Fells are folded along axes east and west, so that it would be very difficult to fold these at right angles by pressure from the west. Hence we should expect that a great pressure from west would move the beds bodily forward, and produce a thrust fault. The Red Conglomerate, which is such a prominent feature in Sedbergh geology, is only found in the eastern district in pockets in hollows of the older rocks. In the central district the complicated, faulted rocks about Bluecaster are similar in general arrangement to the Cross Fell inlier. The Carboniferous Conglomerate needed careful local investigation to decide on the locality of the pebbles, which are often only partially rounded, and are of a size such as would only have been brought by large torrents.

A discussion followed, in which Messrs. A. H. Pawson, W. Robinson, J. Nevin, J. H. Howarth, W. Simpson, D. Forsyth, and E. Hawkesworth took part. The proceedings concluded with a hearty vote of thanks to the lecturer and to Mr. Robinson for his leadership in the Field Excursions.

On Saturday, May 28th, the party drove up Dent Dale to Helmside, with a fine view of the Middleton Fells and Graegreth. There were ample evidences of moraine and other glacial mounds, and indications of overflow valleys. Helm Gill was then ascended, and the inclined beds of Coniston Flags and Limestone examined. At the top of the gorge a mica-trap dyke was examined cutting through the Coniston Limestone series. Higher up the stream fossils were found in these beds, and after working at these for some time with only moderate results, Helm Knott was ascended for the view, which is very extensive. In a quarry on the slope of the Knott, flaggy beds were examined yielding graptolites. The party then returned to Sedbergh, having had a very enjoyable and instructive excursion.

The third General Meeting was held at Barnsley, on Friday, July 8th, under the presidency of the Rev. C. T. Pratt, M.A., and was associated with a series of Field Excursions in the Don and Dearne valleys, conducted by the Hon. Secretary.

On Thursday, July 7th, some useful work was done about the upper waters of the Don in the neighbourhood of Hazlehead Bridge. Bullhouse Colliery was visited, where the Halifax

Hard Bed coal, resting on blue ganister and ganister clay, is worked. The party then ascended Brown's Edge to see Castle Dyke, a circular entrenchment, and from that point a fine view is obtained of the series of grit escarpments which form such a striking feature of the watersheds of the Don and the Little Don. Returning to Hazlehead, the train was taken to Wortley. Walking down the fine gorge of the Don, Deepcar was reached, where a visit was paid to the Lowood Works, where the process of the manufacture of silica and fire bricks was exhibited. Afterwards the fine escarpment known as Wharncliffe Crags was visited, and an examination was made of the numerous examples of false-bedding there to be seen. These rocks afford an instructive lesson on the formation of escarpments. As the grit is undermined by the weathering of the underlying shales, blocks break away from the face along the joint planes, and leave a sharp, perpendicular cliff. From the top of the crags a good view of the winding gorge of the River Don was obtained.

On Friday, July 8th, the party took an early train from Barnsley to Conisbrough, where they were joined by members of the Doncaster Scientific Society. They climbed to the top of Conisbrough Common, whence there is a fine view of the gorge through which the Don flows from Mexborough. Close at hand is the picturesque keep of Conisbrough Castle, made famous by Sir Walter Scott in "Ivanhoe," and in the distance, to the north-west, lies the broad, shallow valley of the Dearne, while the mining village of Denaby can be descried more to the south. Beneath Conisbrough Common, beyond Denaby, is a streamless valley which appears to have been cut by the overflow of a lake formed by the damming of the Don valley at Mexborough by a glacier from the north. Subsequently a visit was paid to the Ashfield Brick Works, where there is exposed a good section of the Middle Coal Measures, with the Lower Magnesian Limestone and Lower Permian Marls above them. Abundant plant remains were noted in the marly beds, and Mr. W. H. Hemingway, of Barnsley, was fortunate enough to find two previously unrecorded species. At the top of this pit is a capping of drift gravel, out of which were taken a volcanic ash from the Lake District, boulders of Carboniferous Limestone, quartz pebbles from the Bunter beds, and Magnesian Limestone boulders. There is a similar deposit of drift at Cadeby, on the slope of the hill at the opposite side of the valley, indicating that at one time the gorge of the Don must have been filled with ice. As the result of the damming up of the waters, a great lake would be formed—a lake which the leader of the expedition (the Rev. W. Lower Carter) held must have extended from Bretton, north of Barnsley, to Chesterfield, a distance of 30 miles. There was not time to visit Conisbrough Castle, but the party walked through the beautiful gorge of the Don towards Doncaster, admiring on the way the fine escarpment in the Magnesian Limestone, with its fringing talus of limestone blocks. Luncheon was taken at Balby, after which a visit was paid to the brick pits, in which are fine sections of stiff boulder-clay (full of erratics), lying on a level eroded surface of Bunter sandstone. According to Mr. Carter's view, the glacier moved through this old depression, scooping out the sandstone, and on its melting left the little valley full of boulder-clay. In confirmation of this theory, Mr. H. H. Corbett reported that when the foundations of the Doncaster Workhouse were dug a section of boulder-clay was exposed, in which were embedded pieces of Bunter sandstone, with every appearance of having been wrenched off with violence. From the Balby brickfields a short walk led to the little lateral valley of Loversal to the south-west of Balby, and draining into the Trent. This valley has been a considerable puzzle to geologists. Mr. Carter's explanation was that when the ice stretched up as far as Edlington and Clifton, the drainage of the central lake, up to 330 feet, would have to pass laterally along the edge of the glacier, and would be diverted down what is now the Loversal valley. This continued until the ice rose to the 350-foot contour, when the gorge was entirely closed. Then the overflow of the great lake took place by another gorge through the Magnesian Limestone, where Kiveton Park Station now is, at 330 feet above sea-level. This ended the day's outing, and the party then took train from Doncaster for headquarters.

The General Meeting was held at the Queen's Hotel, Barnsley, the Rev. C. T. Pratt, M.A., in the chair. Resolutions of regret were passed at the decease of Mr. J. B. Dewhurst (Skipton), who had been a member of the Society since 1879, and of the Rev. John Hawell, M.A., F.G.S. (Ingleby Greenhow), who had been a member since 1887, and for some years the Local Secretary for the Middlesbrough district. Two new members were elected. A paper on "The Geological History of the Don River-system" was read by the Hon. Secretary, and followed by a vigorous discussion in which Professor P. F. Kendall, Messrs. E. Hawkesworth, W. Hemingway, Cosmo Johns, and the Chairman took part. Mr. H. Culpin communicated a paper on "A Fault in the Magnesian Limestone near Cusworth," and the members of the Barnsley Naturalists' Field Club expressed their pleasure at having been invited to take part in the meeting and discussion. The meeting concluded with the usual votes of thanks.

On Saturday, July 9th, a small party drove to Stairfoot, Wombwell, and Wentworth to examine three of the valleys considered by Mr. Carter to be lines of glacier-lake overflow, owing to the damming of the Dearne by a glacier blocking up Frickley Gorge.

The membership of the Society (November 3rd, 1904) is 186, an advance of one on last year's total, eight new members having joined, five resigned, and two, Mr. J. B. Dewhurst and Rev. John Hawell, having been lost by death.

The Rev. W. Johnson, of York, was appointed delegate to the British Association (Cambridge meeting).

A report was received from the Grassington Parish Council—that the finds excavated on Grassington Moor were in the safe custody of the Council, and that Mr. Crowther, the Curator, had arranged the specimens and repaired the cases so that they could be consulted easily by the public.

The Council have selected the following localities for next year's General Meetings and Field Excursions :—

(1) Leeds, in February.

(2) Louth (Lincolnshire) for the study of the Chalk, Kimeridge Clay, Neocomians, and glacial deposits.

(3) S.W. Scotland, for the examination of the Galloway granites and their associated rocks.

(4) Annual Meeting at Wakefield.

The Council report with much pleasure that the long and patient investigation of the underground waters of Ingleborough has now been completed, and the report will be ready for the printer shortly. The heartiest thanks of the Society are due to Mr. A. R. Dwerryhouse, M.Sc., F.G.S., who has devoted so much of his time and strength to this work, and to whose persevering efforts the successful result is largely due.

Our Proceedings have been forwarded to the following Libraries and Scientific Societies in exchange for their publications :—

British Museum, Copyright Office.
British Museum (Natural History).
British Association.
Patent Office Library, London.
Royal Dublin Society.
Royal Geographical Society.
Royal Society of Edinburgh.
Royal Physical Society of Edinburgh.
Royal Society of Tasmania.
Royal Society of New South Wales.
Australian Museum, Sydney, N.S.W.
Department of Mines, Sydney, N.S.W.
Australian Association for the Advancement of Science, Sydney, N.S.W.
Department of Mines, Adelaide, South Australia.
Geological Society of Australasia, Melbourne, Victoria.
Nova Scotian Institute of Science.
Natural History Society of New Brunswick.
Royal Institution of Cornwall, Truro.
Royal Geological Society of Cornwall, Penzance.
Bradford Historical and Antiquarian Society.
Bristol Naturalists' Society.
Birmingham Natural History and Philosophical Society.
Cambridge Philosophical Society.
Essex Naturalists' Field Club.
Edinburgh Geological Society.
Geological Association, London.
Geological Society of London.
Hertfordshire Natural History Society, Watford.
Leeds Philosophical and Literary Society.
Leeds Geological Association.
Liverpool Geological Society.

Liverpool Geological Association.
Hampshire Field Club.
Hull Geological Society.
Hull Scientific and Field Naturalists' Club.
Manchester Geological Society.
Manchester Geographical Society.
Manchester Literary and Philosophical Society.
North of England Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne.
Nottingham Naturalists' Society.
Rochdale Literary and Scientific Society.
Southport Society of Natural Science.
Warwickshire Natural History and Topographical Society.
University Library, Cambridge.
University Library, Glasgow.
Bodleian Library, Oxford.
Radcliffe Library, Oxford.
Yorkshire Naturalists' Union.
Yorkshire Philosophical Society, York.
American Philosophical Society, Philadelphia, U.S.A.
American Museum of Natural History, New York, U.S.A.
Academy of Natural Sciences, Philadelphia, U.S.A.
Academy of Sciences, St. Louis, Mo., U.S.A.
Brooklyn Institute of Arts and Sciences, N.Y.
Boston Society of Natural History, Boston, U.S.A.
Rochester Academy of Sciences, Rochester, N.Y.
Kansas University, Lawrence, Kansas.
Wisconsin Geological and Natural History Survey, Madison, Wis., U.S.A.
Geological Survey of Minnesota, Minneapolis, Minn., U.S.A.
California State Mining Bureau, San Francisco.
Chicago Academy of Sciences.
Maryland Geological Survey, John Hopkins University, Baltimore, U.S.A.
Museum of Comparative Zoology at Harvard College, Cambridge, Mass.
New York Academy of Sciences, New York.
United States Geological Survey, Washington, D.C.
United States National Museum, Washington, D.C.
Elisha Mitchell Scientific Society, University of N. Carolina, Chapel Hill, U.S.A.
University of California, Berkley, California.
Meriden Scientific Association, Meriden, Conn., U.S.A.
New York State Library, Albany, U.S.A.

Wagner Free Institute of Science, Philadelphia, U.S.A.
Wisconsin Academy of Sciences, Arts, and Letters.
Smithsonian Institution, Washington, D.C.
L'Academie Royale Suedoise des Sciences, Stockholm.
Societé Imperiale Mineralogique de St. Petersburg.
Societé Imperiale des Naturalistes, Moscow.
Comité Geologique de la Russie, St. Petersburg.
Instituto Geologico de Mexico.
Sociedad Cientifica "Antonio Alzate," Mexico City.
Naturhistorischen Hofmuseum, Wien, Austria.
Societé d'Emulation d'Abbeville, Abbeville.
L'Academie Royale des Sciences et des Lettres de Danemark, Copenhague.
Royal University of Norway, Kristiania.
Kaiserliche Leopold-Carol. Deutsche Akademie der Naturforscher, Halle-a-Saale.
Geological Institution, Royal University Library, Upsala.
Imperial University of Tokyo, Japan.
Museu Nacional de Rio de Janeiro.

W. LOWER CARTER.

THE YORKSHIRE GEOLOGICAL SOCIETY.

Statement of Receipts and Expenditure, 1st November, 1903, to 1st November, 1904.

REVENUE ACCOUNT.

Dr. — Receipts.

Date	Receipts	£	s.	d.
1903. Nov. 1	To Balance from last year ...	15	0	1
1904. Nov. 1	,, Life Members' Subscriptions transferred from Capital A/c ...	25	4	0
	,, Ordinary Subscriptions ...	65	13	0
	,, Sale of Proceedings ...	3	13	0
	,, Halifax Corporation, Interest on Mortgage Bond ...	11	13	4
	,, Special Fund Subscriptions for illustrating Ingleborough Report ...	5	0	0
		£126	3	5

Cr. — Expenditure.

Date	Expenditure	£	s.	d.
1904. Nov. 1	By Cost of Proceedings (Chorley & Pickersgill)	78	12	9
	,, Sundry Printing, Stationery, Circulars, &c. (Carter) ...	14	18	1
	,, Meetings and Excursions ...	10	18	8
	,, Hon. Secretary's Postages and Petty Cash ...	10	5	1
	,, Stanford, Maps ...	4	19	3
	,, Walker, Geol. Memoir ...	0	10	9
	,, Maps of Pennine Chain for Survey of Western Side ...	3	15	4
	,, Halifax Scientific Society, half cost of block	0	10	0
	,, Spottiswoode & Co. Ltd. ...	0	14	0
	,, Balance in Bank ...	0	19	6
		£126	3	5

CAPITAL ACCOUNT.

Date		£	s.	d.
1904. Nov. 1	To Halifax Corporation Mortgage Bond ...	350	0	0
	,, Life Members' Subscriptions ...	25	4	0
		£375	4	0

Date		£	s.	d.
1904. Nov. 1	By Transfer to Revenue A/c ...	25	4	0
	,, Balance, Halifax Corporation Mortgage Bond	350	0	0
		£375	4	0

Halifax, November 3rd, 1904.

I hereby certify that I have duly audited the above accounts and have examined the vouchers, and found them to be correct.

WM. SIMPSON, *Auditor.*

J. H. HOWARTH,
Hon. Treasurer.

RECORDS OF MEETINGS.

Council Meeting, Philosophical Hall, Leeds, February 25th, 1904.

Chairman :—Mr. Walter Rowley.

Present :—Professor P. F. Kendall, Rev. C. T. Pratt, Messrs. G. Bingley, E. Hawkesworth, A. R. Dwerryhouse, J. W. Stather, and W. L. Carter (Hon. Secretary).

The minutes of the previous Council Meeting were read and confirmed.

Letters of regret for absence were read from Messrs. J. H. Howarth, F. W. Branson, W. Gregson, J. E. Bedford, D. Forsyth, and Revs. E. Maule Cole and J. Hawell.

General Meetings and Field Excursions :—It was resolved to hold a General Meeting at Sedbergh on May 27th and 28th, with an extension to Monday, May 30th. That Mr. W. Robinson, of Sedbergh, be the leader, and Mr. A. R. Dwerryhouse, M.Sc., F.G.S., be the President for the meeting.

It was resolved to postpone the visit to Bury and to take the summer excursion to Barnsley for the examination of the valleys of the Don and Dearne. Date, July 8th and 9th. Leader, Rev. W. Lower Carter, M.A., F.G.S. President, Rev. C. T. Pratt, M.A.

It was resolved to hold the Annual General Meeting at York on, or about, November 3rd, an excursion to the neighbourhood of Market Weighton to be arranged in connection with this meeting.

Proceedings :—The Secretary, in presenting a specimen copy of the Proceedings, Vol. XV., Part I., explained that the delay in its issue had been unavoidable.

A vote of thanks was passed to the Hon. Secretary for the trouble he had taken in preparing an index of the Proceedings, Volumes I. to XIV.

Various papers for Vol. XV., Part 2, were considered, and reports were given as to the probable cost of the illustrations.

Appointments :—The Rev. W. Johnson, B.A., B.Sc., was appointed delegate to the British Association Corresponding Societies' Committee (Cambridge meeting).

The Rev. W. Lower Carter, M.A., F.G.S., was appointed Representative Governor of the Yorkshire College.

The Hon. Secretary reported that he and Mr. J. Lomas, F.G.S., had been appointed Secretaries of Section C (Geology) for the Cambridge meeting of the British Association.

A question was asked as to the representation of the Society on the governing body of the Leeds University, which did not seem to be provided for in the charter. Mr. Rowley promised to inquire into the matter.

The following accounts were passed for payment :—

	£	s.	d.
Halifax Scientific Society (block) ..	0	10	0
F. Carter (circulars and stationery) ..	5	1	0
Do. (mounting maps)	2	17	6
Spottiswoode & Co. (plans)	0	14	0
Stanford (maps)	3	15	4
	£12	17	10

A letter was read from the Grassington Parish Council reporting the safe custody of the ancient British remains.

General Meeting and Field Excursion, Leeds, February 25th, 1904.

A Field Excursion was taken to Meanwood, under the leadership of the Rev. W. Lower Carter, M.A., F.G.S., to examine a section in the ganister beds of the Lower Coal Measures and the gorge at Weetwood through the Millstone Grit.

The members attended, by invitation, a lecture at the Philosophical Hall by Mr. H. Crowther, F.R.M.S., to the children of the Leeds elementary schools, on " Wonders of Insect Life."

The General Meeting was held at the Church Institute, Leeds, under the presidency of Mr. Walter Rowley, F.S.A., F.G.S.

The following new members were elected :—

Alderman J. T. Simpson, Halifax.
Mr. John Pollard, M.I.C.E., Wakefield.
Mr. Joseph J. Burton, Nunthorpe.
Mr. E. T. Edwards, B.Sc., Leeds.

An address on "The Science and Use of Mining" was delivered by the Chairman.

A lecture on "The White Chalk of Yorkshire" was delivered by Mr. Arthur W. Rowe, M.S., M.B., F.G.S., of Margate, illustrated by lantern slides. The lecture was followed by a discussion in which Messrs. P. F. Kendall, J. Burnett, and J. W. Stather took part, and Mr. Rowe replied.

Votes of thanks were passed to the Lecturer and the Chairman.

General Meeting and Field Excursion, Sedbergh, May 27th to 30th, 1904.

Friday, May 27th.—The party, under the guidance of Mr. W. Robinson, examined the unconformity between the Coniston Grits and the basement Carboniferous Conglomerate at Castlehaw Gill and again near Hebblethwaite Hall. The western slope of Baugh Fell was then traversed to Thwaites Gill and an examination was made of mica-trap and felsite dykes on the slopes of Fox Hole Rigg.

The General Meeting was held at the White Hart Hotel, Sedbergh, under the presidency of Mr. A. R. Dwerryhouse, M.Sc., F.G.S.

The minutes of the previous meeting were read and confirmed.

Mr. George F. Townend, of Colne, was elected a member.

Letters of regret for absence were read from Messrs. W. Ackroyd, E. D. Wellburn, and C. W. Fennell.

The following resolution was proposed by the Rev. C. T. Pratt, M.A., seconded by the Hon. Secretary, and carried :—
"That the Secretary be desired to convey to the Rev. John Hawell, M.A., F.G.S., the sincerest sympathy of the members with him in his illness, of which they have heard with much concern, and their earnest hope for his recovery."

An address was delivered by the Chairman on "The Geological Structure of Sedbergh and District," illustrated by a large map.

An interesting discussion followed, in which Messrs. W. Robinson, J. H. Howarth, and W. L. Carter took part.

The proceedings closed with hearty votes of thanks to the Chairman and leader of the Field Excursions.

General Meeting and Field Excursion, Barnsley, July 7th to 9th, 1904.

Thursday, July 7th.—A visit was paid to Bullhouse Colliery, and thence Brown's Edge was ascended to see Castle Dyke, a circular entrenchment, and the extensive view of the watersheds of the Don and the Little Don, with their fine series of grit escarpments. The train was then taken to Wortley and a visit was paid to the Lowood Works at Deepcar. The party climbed Wharncliffe Crags, noted the wonderful false-bedding of the grit, and enjoyed the fine view of the Don gorge.

Friday, July 8th.—The party, under the leadership of the Rev. W. Lower Carter, M.A., F.G.S., went by train to Conisbrough, where they were joined by some members of the Doncaster Scientific Society. Conisbrough Common was climbed for the fine view over the Don and Dearne valleys. Ashfield Brick Works were then visited, where the section of Middle Coal Measures overlaid by Permian marls and drift was examined. The party then walked through the gorge to Balby and examined the boulder-clay pits under the guidance of Mr. H. H. Corbett.

The General Meeting was held at the Queen's Hotel, Barnsley, under the chairmanship of the Rev. C. T. Pratt, M.A.

The minutes of the previous General Meeting were taken as read.

Letters of regret for absence were received from Messrs. C. W. Fennell, G. Bingley, J. H. Howarth, W. Simpson, and A. R. Dwerryhouse.

Resolutions of regret were passed at the decease of Mr. J. B. Dewhurst (Skipton), who had been a member of the Society since 1879, and of the Rev. John Hawell, M.A., F.G.S. (Ingleby Greenhow), who had been a member since 1887 and the Local Secretary for the Middlesbrough district.

The following new members were elected :—

Mr. H. Culpin, Doncaster.

Mr. Cosmo Johns, M.I.Mech.E., Sheffield.

A paper was read by the Rev. W. Lower Carter, M.A., F.G.S., on "The Geological History of the Don River-system."

A discussion took place, in which the Chairman, Messrs. P. F. Kendall, E. Hawkesworth, W. Hemingway, and Cosmo Johns took part.

A paper was communicated by Mr. H. Culpin on "A Fault in the Magnesian Limestone near Cusworth."

The members of the Barnsley Naturalists' Field Club expressed their pleasure, by Messrs. Wade and Bayford, at being invited to the meeting, and their interest in the subject.

A vote of thanks to the Leaders of the Field Excursions the Readers of the Papers, and the Chairman concluded the proceedings.

Saturday, July 9th.—The party drove to Stairfoot, examined the dry valley, and afterwards proceeded to Wombwell and Wentworth to see other cuts through the watershed, after which they returned to Barnsley.

Meeting of the Underground Waters' Committee (*Ingleborough*), Philosophical Hall, Leeds, July 15th, 1904.

Chairman :—Mr. F. W. Branson.

Present :—Messrs. C. W. Fennell, A. R. Dwerryhouse, P. F. Kendall, and W. L. Carter (Hon. Secretary).

The minutes of the previous Committee Meeting were read and confirmed.

Mr. Dwerryhouse reported the concluding work of the Ingleborough investigations. The Shooting Box stream had now been traced to Crummack Beck Head. The courses of several streams previously undetermined had now been ascertained.

It was resolved to appoint an Editorial Committee to prepare the final report for publication, to consist of Messrs. A. R. Dwerryhouse, G. Bingley, J. H. Howarth, and W. L. Carter (Hon. Secretary).

Council Meeting, Philosophical Hall, Leeds, September 22nd, 1904.

Chairman :—Mr. W. Simpson.

Present :—Messrs. J. E. Bedford, E. D. Wellburn, F. F. Walton, P. F. Kendall, J. E. Wilson, J. H. Howarth, A. R. Dwerryhouse, E. Hawkesworth, and W. L. Carter (Hon. Secretary).

The minutes of the previous Council Meeting were read and confirmed.

Letters of regret for absence were read from Messrs. J. T. Atkinson. W. Gregson, G. Bingley. W. Rowley, J. W. Stather, and Rev. C. T. Pratt.

Letters acknowledging the resolutions of the Council on the decease of Mr. J. B. Dewhurst and the Rev. J. Hawell were read from Mr. Dewhurst's family and Mrs. Hawell.

The arrangements for the Annual Meeting at York were considered. It was resolved that the officers and Council be nominated as before with the exception of the following alterations :—

Mr. J. T. Atkinson, F.G.S., having resigned his seat on the Council to be nominated as a Vice-president.

Mr. W. Simpson, F.G.S., to be nominated for the vacant seat on the Council.

Mr. J. W. Sutcliffe to be invited to accept the position of local Secretary for Halifax in the place of Mr. Wm. Simpson resigned.

Resolved that a Field Excursion be arranged in the neighbourhood of York on the morning of the day of the meeting (November 3rd). Also that an Excursion to Market Weighton be arranged for Friday, November 4th, to be led by Professor Kendall.

Proceedings, Vol. XV., Part 2.—The Hon. Secretary reported that the Underground Waters' Report was in preparation and would be completed shortly ; that Messrs. Jowett and Muff's paper on "The Glaciation of Airedale" would be soon ready for the printer ; and that an account of the Cromer and

Norwich Excursion, with a summary of his views on the Glaciation of East Anglia, had been prepared by Mr. F. W. Harmer, F.G.S. It was resolved that an "In Memorian" notice of the Rev. John Hawell, M.A., F.G.S., illustrated with portrait, be issued with this part.

The question of the cost of illustrations and maps was then considered. Mr. Dwerryhouse reported that several maps and photographs would be needed to do justice to the Ingleborough report. It was hoped, however, that part of the cost would be met by special subscriptions. A letter was read from Mr. Jowett asking for a large map of Airedale, a small map of the Bradford Basin, and some photographs. This application was granted. Mr. F. W. Harmer's application for a series of photographs to illustrate his paper was considered. It was felt that the funds of the Society would not permit of the publication of more than six plates. With regard to the proposed publication of Searles Wood's old glacial map, the Council regretted they had not the funds to undertake this, but would be willing to publish it, and any additional photographs, at Mr. Harmer's expense.

General Meetings and Field Excursions :—Resolved that a meeting be held at Leeds in February.

The following Meetings and Field Excursions were also suggested :—

(1) Louth.—For the Chalk, Kimeridge Clay, Neocomians, and glacial deposits.

(2) S.W. Scotland.—For the examination of the Galloway granites, with a view to the better identification of boulders in drift deposits.

(3) Annual General Meeting at Wakefield.

The following accounts were passed for payment :—

	£	s.	d.
F. Carter (circulars and stationery) ..	6	19	7
Chorley & Pickersgill (Proceedings) ..	78	12	9
E. Stanford (maps)	4	19	3
	£90	11	7

Annual General Meeting, the Museum, York, November 3rd, 1904.

Chairman :—J. T. Atkinson, Esq., F.G.S.

The Secretary read a letter from the Marquis of Ripon, regretting his inability to be present.

The Hon. Secretary read an abstract of the Annual Report.

The Treasurer presented the Financial Statement.

Resolution I.—"That the Annual Report and Balance Sheet as presented be adopted and printed in the Proceedings." Proposed by Mr. E. Hawkesworth, seconded by Mr. G. Bingley, and adopted.

The following new members were elected :—

Mr. R. H. Rastall, B.A., F.G.S., Whitby.
Rev. G. H. Brown, Settle.
Mr. E. E. Gregory, Bingley.
Rev. J. C. Fowler, M.A., F.G.S., Whorlton.

Resolution II.—"That the best thanks of this Annual Meeting be given to the President, the Vice-presidents, the Officers, and the Members of the Council, for their successful conduct of the affairs of the Society for the past year." Proposed by Mr. W. Robinson, seconded by Mr. J. Norton Dickons, and adopted.

Resolution III.—"That the Officers and Council as nominated be elected to serve for the forthcoming 12 months." Proposed by Mr. Alfred Sykes, seconded by Mr. J. Lomas, F.G.S., and adopted.

President :

The Marquis of Ripon, K.G.

Vice-Presidents :

Earl Fitzwilliam.
Earl of Wharncliffe.
Earl of Crewe.
Viscount Halifax.
H. Clifton Sorby, LL.D., F.R.S.
Walter Morrison, J.P.
Sir W. Spencer Stanhope, K.C.B.

James Booth, J.P., F.G.S.
F. H. Bowman, D.Sc., F.R.S.E.
W. H. Hudleston, F.R.S., F.G.S.
J. Ray Eddy, F.G.S.
David Forsyth, D.Sc., M.A.
Walter Rowley, F.G.S., F.S.A.
Lord Masham.
Sir Christopher Furness, M.P., D.L.
J. T. Atkinson, F.G.S.

Treasurer :

J. H. Howarth, F.G.S.

Hon. Secretary :

William Lower Carter, M.A., F.G.S.

Hon. Librarian :

Henry Crowther, F.R.M.S.

Auditor :

W. Simpson, F.G.S.

Council :

W. Ackroyd, F.I.C.
J. E. Bedford, F.G.S.
Godfrey Bingley.
F. W. Branson, F.I.C.
W. Cash, F.G.S.
A. R. Dwerryhouse, F.G.S.
Edwin Hawkesworth.
P. F. Kendall, F.G.S.
Rev. C. T. Pratt, M.A.
W. Simpson, F.G.S.
F. F. Walton, F.G.S.
E. D. Wellburn, F.G.S.

Local Secretaries :

Barnsley—T. W. H. Mitchell.
Bradford—J. E. Wilson.
Driffield—Rev. E. M. Cole, M.A., F.G.S.
Halifax—J. W. Sutcliffe.
Harrogate—Robert Peach.
Hull—John W. Stather, F.G.S.
Leeds—H. Crowther, F.R.M.S.
Sheffield—Cosmo Johns, M.I.Mech.E.
Skipton—J. J. Wilkinson.

Thirsk—W. Gregson, F.G.S.
Wakefield—C. W. Fennell, F.G.S.
Wensleydale—W. Horne, F.G.S.
York—Rev. W. Johnson, B.A., B.Sc.

The Chairman delivered an address.

The following papers were read :—

"Final Report of the Committee for the Investigation of the Underground Waters of Ingleborough." By Arthur R. Dwerryhouse, Esq., M.Sc., F.G.S.

"Earth Movements which have affected the Cleveland Area." By Professor Percy F. Kendall, F.G.S.

"Notes on the Vertical Distribution of East Yorkshire Boulders." By John W. Stather, Esq., F.G.S.

"Recent Investigations respecting the Glacial Lakes in the Areas adjoining Airedale." By E. E. Gregory, Esq. Illustrated by lantern slides.

Each paper was followed by a discussion.

Resolution IV.—"That the best thanks of this Annual Meeting be given to the Chairman for presiding; to the Yorkshire Philosophical Society, for the use of the Museum; to Mr. Platnauer for his kind assistance in arranging the meeting; to the Leaders of the Field Excursions; and to the Readers of the Papers." Proposed by Rev. C. T. Pratt, seconded by Mr. F. W. Branson, and adopted.

The members and their friends dined together at Harker's Hotel.

In the evening a lecture was delivered at the Museum by Professor P. F. Kendall, F.G.S., on "The First Men in Britain," illustrated by lantern slides. The members of our Society were present by the kind invitation of the Yorkshire Philosophical Society.

In connection with the Annual General Meeting the following Field Excursions were taken :—

(i.) November 3rd.—Leader, Rev. W. Johnson, B.A., B.Sc. To Dringhouses brick-pits, where finely laminated silt overlying gravel beds was seen. Thence to the York Racecourse, near which sections of sand and gravel, overlaid by boulder-clay, were examined.

(ii.) November 4th.—Leaders, Professor P. F. Kendall, F.G.S., and Mr. J. W. Stather, F.G.S.

Train to Market Weighton and on to Middleton-on-the-Wolds. The party visited Middleton Whiting Works, inspected the deep chalk pit, and observed a glacial overflow near at hand.

The party then walked through Middleton and followed a long, winding overflow valley, which formed an aligned sequence of channels, draining the ice-front and discharging at Kipling Cotes into a large valley, which cuts through the watershed to Market Weighton. An extensive excavation showed the old valley side, against which the chalk gravels were banked up, and a side valley filled with gravel. Near Market Weighton the Red Chalk was seen on the roadside, and the Lower Lias in an adjoining brick pit.

(iii.) A small party started from Market Weighton, and visited the shooting range at Goodmanham. The section here shows Red Chalk overlaid by Grey Chalk with pink bands, and in the pit below, Lower Lias.

The large gravel pit was revisited and the sections examined. Brown bands were noted and examined, which proved to be full of minute calcareous tubes, secreted by fine rootlets, some of which were found still filling the tubules.

A traverse of the Wolds was then made to North Newbald, evidences of drift deposits being found on the way, and the terraces of the Newbald valley were noted.

HONORARY MEMBERS.

1887 Bodington, N., Litt.D., Vice-Chancellor, The University, Leeds.

1892 De Rance, Chas. E., C.E., F.R.M.S., 32, Carshalton Road, Blackpool.

1887 Hughes, Prof. T. McK., M.A., F.R.S., F.G.S., Ravensworth, Brooklands Avenue, Cambridge.

1887 Judd, Prof. Jno. W., C.B., LL.D., F.R.S., F.G.S., 22, Cumberland Road, Kew, Surrey.

1887 Woodward, Henry, LL.D., F.R.S., British Museum (Natural History), Cromwell Road, London, S.W.

1898 Whitaker, William, B.A., F.G.S., F.R.S., Freda, Campden Road, Croydon.

LIST OF MEMBERS.

* Life Members who have compounded for the annual subscriptions.

Elected.

1883*Abbott, R. T. G., Whitley House, Malton.

1903 Ackroyd, Wm., M.E., F.I.I., Nan Tan, Wortley, Leeds.

1901*Anderson, Tempest, M.D., F.G.S., 17, Stonegate, York.

1899 Appleyard, J. H. R., B.Sc., 5, Willow Lane East, Huddersfield.

1900 Ashley, Theodore, Ivy House, Bakewell Street, Coalville, near Leicester.

1900 Ashworth, John Hoyle, Wood Rhydding, Ilkley.

1875 Atkinson, J. T., F.G.S., Hayesthorpe, Holgate Hill, York.

1879*Bartholomew, C. W., Blakesley Hall, near Towcaster.

1899 Bean, J. A., F.G.S., Moot Hall, Newcastle-on-Tyne.

1878 Bedford, J. E., F.G.S., Arncliffe, Shire Oak Road, Headingley, Leeds.

1903 Beverley, Robert B., Heath House, Wakefield.

1895 Bingley, Godfrey, Thorniehurst, Shaw Lane, Headingley, Leeds.

1875*Booth, James, J.P., F.G.S., Spring Hall, Halifax.
1905 Booth, John, 15, School Hill, Windhill, Shipley.
1899 Bould, Chas. H., 4, Welton Place, Hyde Park, Leeds.
1876*Bowman, F. H., D.Sc., F.R.A.S., F.C.S., Spinningfield, Deansgate, Manchester.
1896 Bradley, F. L., Ingleside, Malvern Wells.
1894 Branson, F. W., F.I.C., F.C.S., 14, Commercial Street, Leeds.
1875*Brigg, John, M.P., F.G.S., Kildwick Hall, Keighley.
1901 Briggs, Arthur N., Messrs. Milligan, Forbes & Co., Bradford.
1905 Brodrick, Harold, M.A., 7, Aughton Road, Birkdale, Lancs.
1877 Brooke, Sir Thos., Bart, J.P., Armitage Bridge, Huddersfield.
1904 Brown, Rev. G. H., Pendle View, Giggleswick, *viâ* Leeds.
1887 Brownridge, C., M.Inst.C.E., F.G.S., 26, North Road, Devonshire Park, Birkenhead.
1882*Buckley, George, Waterhouse Street, Halifax.
1896 Burrell, B.A., F.I.C., F.C.S., 8, Springfield Mount, Leeds.
1904 Burton, Jos. J., Rosecroft, Nunthorpe, R.S.O.
1901 Canham, Rev. Henry, LL.B., F.G.S., 19, Vernon Road, Leeds.
1903 Carlton, John, 48, Albany Street, Hull.
1905 Carpenter, F. G., Savile House, Stanley Road, Wakefield.
1900 Carr, Professor J. W., M.A., F.L.S., F.G.S., University College, Nottingham.
1892*Carter, W. Lower, M.A., F.G.S., Hopton, Mirfield.
1876*Cash, W., F.G.S., 35, Commercial Street, Halifax.
1891*Chambers, J. C., Edgerton Road, West Park, Leeds.
1875*Charlesworth, J. B., J.P., Hurts Hall, Saxmundham.
1892*Childe, Hy. Slade, F.G.S., Mining Engineer, Wakefield.
1903 Chippendale, Amos, Sindale House, Harrogate.
1877*Clark, J. E., B.A., B.Sc., Asgarth, Riddlesdown Road, Purley, Surrey.
1875 Cole, Rev. E. Maule, M.A., F.G.S., Wetwang Vicarage near York.
1903 Cragg, Richard B., Solicitor, Skipton.

1889 Crewe, Earl of, Crewe Hall, Crewe.
1897 Crofts, William Hastings, 16, Ash Grove, Newland, Hull.
1899 Crossley, Abraham, 62, Wellington Road, Todmorden.
1894 Crowther, Henry, F.R.M.S., The Museum, Leeds.
1899 Crump, W. B., M.A., 39, Aked's Road, Halifax.
1904 Culpin, H., 36, Netherhall Road, Doncaster.
1899 Dalzell, A. E., 3, Wesley Court, Crossley Street, Halifax.
1879*Dakyns, J. R., M.A., Snowdon View, Gwynant, Beddgelert, Carnarvon.
1883 Dalton, Thos., 65, Albion Street, Leeds.
1894*Davis, James Percy A., Chevinedge, Halifax.
1903 Davis, A. H., M.A., Wharfedale School, Ilkley.
1900*Dickons, J. Norton, 22, Park Drive, Heaton, Bradford.
1902 Dixon, Ed. Wilson, M.Inst.C.E., 14, Albert Street, Harrogate.
1886*Dobinson, Launcelot, Park View, Stanley, near Wakefield.
1887*Duncan, Sir S. W., Bart., Horsforth Hall, Leeds.
1896 Dwerryhouse, Arthur R., D.Sc., F.G.S., 5, Oakfield Terrace, Headingley, Leeds.
1879 Eddy, J. Ray, F.G.S., Carleton Grange, Skipton.
1904 Edwards, E. J., M.Sc., 12, Norwood Terrace, Headingley, Leeds.
1905 Elliot, Sir Charles, K.C.M.G., C.B , Vice-Chancellor, The University, Sheffield.
1894 Embleton, Henry C., Central Bank Chambers, Leeds.
1895*Farrah, John, F.R.Met.S., Jefferies Coate, York Road, Harrogate.
1903 Farrah, John Wm., Jefferies Coate, Harrogate.
1887*Fennell, Chas. W., F.G.S., 82, Westgate, Wakefield.
1902 Fitzwilliam, Earl, Wentworth Woodhouse, near Rotherham.
1883*Fleming, Francis, Elm Grove, Halifax.
1893 Forsyth, David, D.Sc., M.A., 101, Caledonian Road, Leeds.
1904 Fowler, Rev. J. C., M.A., F.G.S., Whorlton Vicarage, near Northallerton.
1894 Fox, C. E., P.A.S.I., 22, George Street, Halifax.
1891*Furness, Sir Christopher, M.P., Brantford, West Hartlepool.

1890 Garforth, W. E., C.E., F.G.S., Snydale Hall, Pontefract.
1905 Glauert, Ludgwig, Jun., F.G.S., 21, Kenwood Park Road, Sheffield.
1881 Gleadow, F., 38, Ladbroke Grove, London, W.
1905 Grace, George, B.Sc., Oak Mount, Lawn Road, Doncaster.
1899 Greaves, A. E., St. John's, Wakefield.
1904 Gregory, E. E., Thornfield Cottage, Bingley.
1878 Gregson, W., F.G.S., Gainford-on-Tees, Darlington.
1905 Green, H. G. H., Claremont, Bradford Road, Wakefield.
1905 Hadfield, R. A., M.Inst.C.E., Parkhead House, Ecclesall, Sheffield.
1898 Haldane, George W., M.E., Old Corn Exchange, Wakefield.
1843 Halifax, Viscount, Hickleton Hall, Doncaster.
1905 Halton, George, 13, Regent Park Terrace, Headingley, Leeds.
1895 Harker, Alfred, M.A., F.R.S., F.G.S., St. John's College, Cambridge.
1905 Hartley, R. T., M.I.Mech.E., Borough Waterworks Engineer, Halifax.
1887 Hastings, Geoffrey, 15, Oak Lane, Bradford.
1896 Hawkesworth, Edwin, Sunnyside, Crossgates, near Leeds.
1905 Hill, Charles Alexander, M.B., D.Ph., 13, Rodney Street, Liverpool.
1900*Hind, Wheelton, M.D., F.G.S., Roxeth House, Stoke-on-Trent.
1905 Hodges, Isaac, Whitwood, Normanton.
1881 Horne, Wm., F.G.S., Leyburn.
1890*Howarth, J. H., J.P., F.G.S., Somerley, Rawson Avenue, Halifax.
1882*Hudleston, W. H., F.R.S., F.G.S., 8, Stanhope Gardens, South Kensington, S.W.
1902*Ibbotson, John, Fitzalan Square, Sheffield.
1895*Imbery, John, 128, Heathleigh, Halifax.
1903*Ingham, Edward T., J.P., Blake Hall, Mirfield.
1904 Johns, Cosmo, F.G.S., M.I.Mech.E., Burngrove, Pitsmoor Road, Sheffield.

1901 Johnson, Rev. W., B.A., B.Sc., Archbishop Holgate's School, York.

1905 Jones, Rev. E., Embsay.

1887*Jones, J. E., Solicitor, Halifax.

1897 Jowett, Albert, M.Sc., The Technical School, Bury.

1905 Jordan, Albert, St. John's Road, Balby, Doncaster.

1900 Justen, Frederick, F.L.S., 37, Soho Square, London, W.

1892 Kendall, Professor Percy F., M.Sc., F.G.S., 5, Woodland Terrace, Chapel-Allerton, Leeds.

1905 Kenworthy, Joseph, Stretton Villa, Deepcar, near Sheffield.

1902 Kidston, Robert, F.R.S., F.R.S.E., F.G.S., 12, Clarendon Place, Stirling.

1897*Kitson, R. H., F.G.S., Elmet Hall, Leeds.

1877*Lamplugh, G. W., F.R.S., F.G.S., of H.M. Geol. Survey, 13, Beaconsfield Road, St. Albans.

1894 Law, Arthur W., Greetland, Halifax.

1898 Law, Robert, F.G.S., Fennyroyd Hall, Hipperholme.

1903*Lawrence, J. P., A.M.I.C.E., Scriven, near Knaresborough.

1901 Lomas, Joseph, F.G.S., 13, Moss Grove, Birkenhead.

1905 Longbottom, J. Leonard, Dingleside, Gledholt, Huddersfield.

1877*Lupton, Arnold, M.P., F.G.S., M.Inst.C.E., 6, De Grey Road, Leeds.

1905 Macturk, G. W. B., 15, Bowlalley Lane, Hull.

1905 Margerison, Samuel, Grey Gables, Calverley, near Leeds.

1891*Masham, Lord, Swinton Castle, Bedale.

1905 Massie, Frank, A.M.I.C.E., F.S.I., Tetley House, Wakefield.

1905 Milton, J. H., F.R.G.S., College Avenue, Crosby, Liverpool.

1889 Mitchell, T. W. H., 25, Regent Street, Barnsley.

1896 Moreton, Henry James, Station Hotel, Lofthouse, Wakefield.

1879*Morrison, Walter, J.P., Malham Tarn, Settle.

1878 Mortimer, J. R., Driffield.

1894*Muff, H. Brantwood, B.A., F.G.S., Geological Survey Office, Sheriff Court Buildings, Edinburgh.

1895 Muller, Harry, 12, West Chislehurst Park, Eltham, Kent.
1900 Murray, Richard, Barwick-in-Elmet, near Leeds.
1903 Naylor, E., Heather Bank, Hazlehurst Road, Bradford.
1902 Nettleton, Stanley, Roundwood, Ossett.
1898 Nevin, John, J.P., F.G.S., Littlemoor, Mirfield.
1889*Nicholson, M., J.P., Middleton Hall, near Leeds.
1899*Ormerod, William, Kershaw House, Luddendenfoot.
1875*Parke, G. H., F.G.S., F.L.S., St. John's Villas, Wakefield.
1892*Pawson, A. H., F.L.S., F.G.S., Lawns House, Farnley, Leeds.
1905 Pickles, Herbert, B.A., 5, Brudenell Mount, Hyde Park, Leeds.
1904*Pollard, John, F.G.S., 56, Westgate, Wakefield.
1897 Pratt, Rev. Chas. T., M.A., Cawthorne Vicarage, near Barnsley.
1905 Punch, J. W. R., Hastoe House, Southfield Road, Middlesbrough.
1859*Ramsden, Sir J. W., Bart., Byram Hall, near Pontefract.
1904 Rastall, R. H., B.A., F.G.S., Turnerdale Hall, Whitby.
1864*Rhodes, John, Bolton Royd, Bradford.
1856*Ripon, The Marquis of, K.G., F.R.S., &c., Studley Royal, Ripon.
1898 Robinson, William, Greenbank, Sedbergh, R.S.O.
1901 Roebuck, W. Denison, F.L.S., 259, Hyde Park Road, Leeds.
1903*Rowe, Arthur W., M.S., M.B, F.G.S., 1, Cecil Street, Margate.
1902 Rowland, Lewis G., 3, St. Hilda's Terrace, Whitby.
1869*Rowley, Walter, F.G.S., F.S.A., 20, Park Row, Leeds.
1875*Ryder, Charles, Westfield, Chapeltown, Leeds.
1901 Sagar, Joe, The Poplars, Savile Park, Halifax.
1882 Scarborough Philosophical Society, The Museum, Scarborough.
1905 Sewell, J. T., Chubb Hill Road, Whitby.
1897*Sheppard, Thomas, F.G.S., 392, Holderness Road, Hull.
1892*Simpson, W., F.G.S., Catterall Hall, Settle.
1904*Simpson, Alderman J. T., J.P., Brackenholm, Rutland Road, Harrogate.
1887 Slater, M. B., 84, Newbiggin, Malton.

1879 Slingsby, W. C., Carleton, near Skipton.
1876*Smith, F., The Grange, Lightcliffe.
1851 Sorby, H. C., D.C.L., F.R.S., F.G.S., Broomfield, Sheffield.
1901 Spence, Edmund, Clapham, Lancaster.
1875 Stanhope, Sir Walter Spencer, K.C.B., Cannon Hall, Barnsley.
1881*Stansfeld, Alfred W., Dacre House, Rock Ferry, Cheshire.
1900*Stansfield, W. G., Wilton House, The Grove, Ilkley.
1890 Stather, John W., F.G.S., 16, Louis Street, Hull.
1902 Stead, Samuel, 33, James Street, Harrogate.
1894 Stears, John, Westholme, Hessle, near Hull.
1899 Stewart, W. H., Foxwood, Kent Road, Harrogate.
1898*Stewart, William, Brooklyn, Crigglestone, Wakefield.
1885*Stockdale, T., Spring Lea, Leeds.
1878 Strangways, C. Fox, F.G.S., Kylemore, Hollycroft Avenue, Hampstead, London, N.W.
1879*Strickland, Sir Charles W., Bart., Hildenly, Malton.
1902 Stringer, G. E., Junior, Slingsby Hall, York.
1894 Sutcliffe, J. W., The Hollies, Greenroyd, Halifax.
1888 Sykes, Sir Tatton, Bart., Sledmere House, near York.
1902*Sykes, Alfred, Woodville, Thongs Bridge, Huddersfield.
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