29. *A SYSTEM of GLACIER-LAKES in the CLEVELAND HILLS.* By
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I. INTRODUCTORY.

It is now 8 years since I commenced observations upon the Glacial phenomena of the Cleveland area—using the term in its broadest sense as including the whole of the Jurassic mass of North-eastern Yorkshire, but no results were attained in the first 5 years. The investigation, however, of a tract of country on the western edge of the Vale of York familiarized me with many of the more patent signs of old glacier-lakes, especially the phenomena of abandoned overflows, and this experience enabled me to recognize the great Newton-Dale valley as belonging to this category. Following this clue backward, I discovered the great system of lakes and related phenomena now to be described.

The progress of the investigation of the area west of the Ouse has been briefly recorded in papers submitted to the British Association,¹ and on various occasions has been communicated to the Yorkshire Geological & Polytechnic Society.² A new stimulus to these studies was given by Prof. W. M. Davis, who accompanied me

¹ Rep. Brit. Assoc. 1896 (Liverpool) p. 801, & *ibid.* 1899 (Dover) p. 743.

² Proc. York. Geol. & Polyt. Soc. n.s. vol. xii (1893) pp. 306-18, & *ibid.* vol. xiii (1895) pp. 89-91.

in the examination of a tract of country round Knaresborough, where an extra-morainic diversion of the River Nidd and some other lake-overflows are well displayed. Prof. Davis on that occasion mentioned some work of a like nature which was engaging the attention of Prof. G. K. Gilbert; and I am impelled to mention the fact, as this statement of Prof. Gilbert's views undoubtedly aided me, to how great an extent I am unable to say.

II. MODERN EXTRA-MORAINIC 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. Such lakes, from their position, have been termed extra-morainic lakes,¹—a term not wholly free from objection, as some ice-masses are not margined by any recognizable moraine; and, again, some such lakes lie between the lobes or ridges of a moraine. But, with a reservation to cover all these cases, the term may be conveniently adopted.

The Alps furnish few examples of these lakes, as they are best developed where the relief of the country is low and the ice-streams are large. The Mürjelen See is the best known, though not the only, glacier-lakelet of the Alps. It has been admirably described by many writers, the best description in English being that given by Dr. Du Riche Preller.² The present writer has also published some notes upon the lakelet and its floor-deposits.³

Norway, with its more extensive ice-fields, furnishes more numerous and varied examples, such as the Dømmevand described by Capt. A. F. Mockler Ferryman⁴ and Dr. P. A. Ceyen.⁵ It is, however, to the gigantic 'piedmont' 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.

The chain of lakes held up in the Chaix Hills by the ice-stress of the Malaspina Glacier are of great interest, and geologists will welcome a fuller description of them than that contained in Prof. I. C. Russell's masterly memoir.⁶

The great ice-sheet of Grinnell Land sustains marginal lakes of large size, described by Gen. Greely in his 'Three Years of Arctic Service'; but around the lobes of the Greenlandic ice-cap they are to be found in the greatest number and perfection.⁷ I would

¹ Carvill Lewis, Rep. Brit. Assoc. 1887 (Manchester) p. 691.

² Geol. Mag. 1896, p. 97.

³ Glac. Mag. vol. iii (1895) pp. 127-28.

⁴ Geogr. Journ. vol. iv (1894) p. 524.

⁵ Bergens Museums Aarbog (1894-95) no. iii.

⁶ 'Glaciers of North America' Boston, 1897, pp. 118-21.

⁷ T. C. Chamberlin, 'Glacial Studies in Greenland' Journ. of Geol. vols. ii, iii, & iv (1894-96).

refer especially to Prof. R. S. Tarr's brief but highly interesting account of the lakelets that fringe the Cornell Glacier on the Nugsuak Peninsula.¹ Prof. Tarr furnishes a description of the deltas and floor-deposits of these lakelets, which will be found of great value for comparison with the relics of similar lakelets in Britain.

III. PLEISTOCENE LAKES, AND THE CRITERIA FOR THEIR RECOGNITION.

It might have been predicted that proofs would be forthcoming that extra-morainic lakes of Pleistocene age had prevailed over areas extensive in proportion to the great magnitude of the ice-sheets. Traces of several such lakes have been recognized, the most important of which is, undoubtedly, the gigantic Lake Agassiz, the waters of which covered half a million square miles in North America. This lake has a claim to consideration, apart from its mere magnitude, as it appears to have been first in order of discovery as well as in point of size. Keating inferred the presence of a lake on this site so long ago as 1823, but probably to Gen. Warren should belong the credit of clearly demonstrating its existence. A noteworthy series of lesser lakes in the neighbourhood of Rochester (N.Y.), has been well described by Mr. H. L. Fairchild,² and the investigations of Prof. G. K. Gilbert upon a similar series have been referred to. Many other examples in North America have been described. The only lakes having such an origin that have been recognized in this country, so far as I am aware, are:—a lake enclosed in the valley of the Black Cart, behind (south of) Glasgow, identified by my lamented friend the late Mr. Dugald Bell of Glasgow,³ and independently by Prof. James Geikie⁴; another in the valley of the Tweed, also discovered by Prof. Geikie⁵; the Glen-Roy Lakes, the lacustrine nature of which was first conclusively shown by Mr. T. F. Jamieson⁶; a great lake in the Vale of Pickering, postulated upon very inconclusive grounds by Phillips and other writers, but demonstrated in a very clear and convincing manner by Mr. C. Fox-Strangways⁷; and a great series of extra-morainic lakes described by the late Prof. Carvill Lewis.⁸

The criteria by which ancient extra-morainic lakes can be recognized are mainly four:—(1) beaches; (2) deltas; (3) floor-deposits; and (4) overflow-channels. But to these might be added the *a priori* arguments of Prof. Carvill Lewis, who considered that the existence of lakes could be deduced from the ascertained position of the ice-front, a process of deduction upon which I have never relied, except when reinforced by the direct testimony of one or more

¹ Amer. Geol. vol. xx (1897) pp. 150 *et seqq.*

² Am. Journ. Sci. ser. 4, vol. vii (1899) pp. 249-63.

³ Trans. Geol. Soc. Glasgow, vol. iv (1874) p. 66.

⁴ 'Great Ice Age' 1st ed. (1874) pp. 186 *et seqq.*

⁵ *Ibid.* 2nd ed. (1877) p. 144.

⁶ Quart. Journ. Geol. Soc. vol. xix (1863) p. 235.

⁷ Mem. Geol. Surv. 'Jurassic Rocks of Britain' vol. i (1892) p. 423.

⁸ Rep. Brit. Assoc. 1887 (Manchester) p. 692.

of the phenomena mentioned above. Mr. Warren Upham, in his masterly monograph upon the glacial Lake Agassiz,¹ has reviewed these criteria with his customary clearness; but, although his descriptions may be confidently recommended for study by British geologists, they deal with phenomena upon a scale of magnitude so far transcending that upon which such features are developed in Britain, that I am constrained to furnish a brief account more applicable to experience in this country. Moreover, Mr. Upham addresses a scientific public which is practically unanimous in accepting his premises of great confluent glaciers, and in rejecting the suggestion of marine action as a cause of the bulk of the Pleistocene deposits, whereas, in Britain, these views have not as yet received unanimous sanction.

(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 static waters; but no absolute proof, apart from included organisms, can be adduced to show whether sea- or fresh-water was the agent.

The little Mürjelen See is margined by an excellently defined beach, consisting for the most part of an arrested talus of large angular blocks which have rolled or crept down the adjacent mountain-sides, with some blocks rafted out by floating ice. The upper level of the beach coincides with that of the col across which the overflow takes place, or did formerly take place (that is, before the great drainage-tunnel was made by the Cantonal authorities). The series of lakes in the Glen-Roy district was recognized solely by the evidence of such beaches, which form a series of sensibly horizontal benches along the mountain-sides, so conspicuous as to have become the subject of a popular legend. Mr. Jamieson demonstrated that they were the strand-lines of ice-dammed lakes, chiefly by the evidence of the coincidence of their respective altitudes with those of the cols across which drainage could have occurred. The beaches of Lake Agassiz are upon a vast scale, and show a noteworthy deformation in a vertical sense: they do not consist of arrested talus merely, but are composed of sand and well-rolled shingle. Mr. Fox-Strangways found few signs of the beaches of his Lake Pickering; and I am unable to cite a single well-marked example in the Cleveland area, where, if the conditions had been favourable, there should be hundreds, each representing either a separate lake or a separate phase of a particular lake. Shore-scarps are quite common, but they are (with two or three exceptions) impersistent. I have seen in several places sections in these scarps, and these will be mentioned in the sequel. Some show well-bedded dirty gravel, and in others a rubble of angular and rounded fragments of local rock with some foreign stones, all resting against a greatly-shattered face of sandstone. Occasionally the hillsides are seen to be furrowed by many scarps half-obliterated by weathering or by the action of the plough,

¹ Monogr. U.S. Geol. Surv. vol. xxv (1896).

and running at different levels for 1 or 2 furlongs. The reason for this general absence or imperfect development of beach-lines in the Cleveland area admits of a very simple and natural explanation. For their production, stability of the water-level during a considerable period is one of the great requisites, abundance of beach-forming material the other. The occurrence of successive sea-beaches round the coasts of Scotland and Norway does not imply that the land rose *per saltum*, but rather that there were protracted periods of comparative repose and beach-formation, followed by periods of movement, slow, yet sufficiently rapid to prevent the accumulation of a recognizable beach. Again, the beaches are not horizontally continuous, but are interrupted where the supply of beach-making material was deficient.

In the case of a glacier-lake, the stability of the level will be determined by the constancy of the position and altitude of the ice-dam, and the rate of erosion of the channel by which the overflow takes place. The former factor cannot in the generality of cases be evaluated, but the latter is much more easily determined. It will depend upon the volume of water to be carried, the fall, and the nature of the rock at the overflow. In the cases of both the Mårjelen See and the Glen-Roy Lakes, the overflow takes place (or took place) over hard crystalline rock, which is very slowly eroded, and consequently the lake-levels were very stable and the beaches are large and well-defined. The overflows of the Cleveland Lakes were over Jurassic rocks, for the most part soft shales; hence they were cut down rapidly, and little or no beach-formation resulted. In a few cases the sills were cut down on to hard beds of grit; and it is at levels coincident with these that the best-defined strand-lines occur.

(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 highwater 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.

Mr. Jamieson, and observers who preceded him, found that the deltas of streams flowing into the Glen-Roy Lakes were very well-defined at the point where they coalesced with the beaches. In the Cleveland area such deltas are rarely seen, but some examples exist, especially in the valley of the Esk. They occasionally exhibit the fanlike 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.—The late Mr. Dugald Bell and Prof. James Geikie have alluded to the deposits which accumulated upon the floor of the Black-Cart Lake; and the late Prof. Carvill Lewis made reference to the nature of the deposits accumulated in

the extra-morainic lakes identified by him. I shall endeavour to show that he was correct in the ascription of the Warp-clays of the Vale of Pickering to a lacustrine origin as well as the older Warps of the Vale of York. On the other hand, I was impelled, some years ago,¹ to dissent from his identification of the great Chalky Boulder-Clay with lacustrine deposits, an opinion which he shared with the Rev. Edwin Hill. Recent experience has greatly strengthened my conviction that that remarkable deposit was laid down by the direct agency of land-ice. Mr. Fox-Strangways expressed the opinion that the Warp and other alluvium of the Vale of Pickering was either of lacustrine or estuarine origin.

It will be seen that, in this country, considerable uncertainty prevails regarding the materials which might be accumulated under lacustrine conditions; and I may well at this stage define my own position upon the question, with specific reference to the accumulations in glacier-lakes.

I have had the opportunity of examining the deposits of two well-known lakelets held up by glacier-ice in the Alps, namely, the Gorner See and the Märjelen See. The former of these is mainly super-glacial in position: it lay in 1894 in the angle formed by the confluence of the Grenz and Monte Rosa Glaciers, tributaries of the Gorner, and its floor was composed chiefly of ice, though along one of its free sides it abutted upon a spur of Monte Rosa, and the right lateral moraine and rock-train of the Grenz Glacier descended beneath the water. The waters of the lake are prone to rapid lowering of level at very irregular intervals, dependent upon the production of the crevasses by which they are drawn off. I have at one season seen the shallow basin filled almost to the point at which it would flow off over the ice, and at another season have found the icy bed almost completely exposed, with large blocks of ice lying stranded near the old margin. On both occasions I observed that, besides the large masses of rock from the rock-train which were strewn promiscuously about, the deserted bed was covered with a deposit of very fine mud, perhaps glacier-meal washed in by a stream flowing beside the Grenz Glacier.

At the time of my visit to the Märjelen See, the lakelet was approaching the condition of repletion which would bring into action the new artificial drain, but there was still a large area of its floor exposed. This was mainly composed of a bouldery-rubble covered with a film of fine mud, but in some hollows I found a gritty clay with stones, resembling ordinary moraine-stuff.

Thus far only extends my personal experience of the deposits of modern glacier-lakes; but Prof. Chamberlin, in his valuable papers on the Greenlandic glaciers, and Prof. Tarr, in his description of the Cornell Glacier of the Nugsuak Peninsula, have furnished data of the greatest value relative to the floor-deposits of some of the countless glacier-dammed lakes of the Arctic regions. Reference

¹ 'Man & the Glacial Period,' by G. F. Wright, Internat. Sci. Series, 1892, p. 159.

must also be made to the fjord-muds so well described by Rink and others, for these muds, though accumulated under tidal conditions, must have many features in common with the deposits of glacier-lakes.

The study of lacustrine formations other than those of glacier-lakes is also germane to the present enquiry, for the differences will be only in the details, and especially in two of them—the amount and character of the mud, and the presence and character of included organic remains. Reference may therefore be made to the extensive literature of limnology, and especially to Prof. F. A. Forel's monograph '*Le Léman*' vol. i (1892) pp. 101–139; Dr. H. R. Mill's valuable description of the English Lakes¹; and Mr. Upham's monograph on Lake Agassiz.²

The Lake of Geneva, which differs from the largest of British Pleistocene lakes chiefly in the absence of any direct contact with the glaciers that feed it, might be taken as a typical area of lacustrine accumulation, and a general description of its floor-deposits will be helpful to our understanding of the general conditions of deposition.

At the point where the Rhône debouches into the lake, near Villeneuve and Bouverie, the river casts down its great load of shingle, and is gradually pushing its mouth forward into the lake. Beyond the gravel, finer materials are cast down within a short distance of the mouth of the river; and beyond this again the fine glacier-mud, with which the Rhône is so heavily charged, is wafted on and laid down over a wide area as a deposit of impalpable mud of exceeding fineness. The seasonal and diurnal augmentations of volume which affect the Rhône, must carry sediments of a different grade out to the regions of finest sediment, and so it might be anticipated that the fine clays would show interlaminations of coarser material. Interlaminations of materials differing more in colour than in texture must also occur. The bed of the Lake of Geneva is not sufficiently well exposed to enable me to support these generalities by actual observation, but fine laminated muds have been found in the exploration of lake-dwellings in seasons of exceptional dryness, when the lake-levels were lowered.

If the Lake of Geneva were held up by an ice-dam, as the Märjelen See is, we might expect to find stony clays, resembling those of the Märjelen See, and perhaps actual moraine, accumulating near the ice; while farther away laminated clays might be expected to prevail, and to contain occasional stones, large and small, which had been rafted out by bergs breaking off from the ice-front or by shore-ice. Such sporadic boulders and pebbles do occur sparsely in some of the Warps of Yorkshire.

Some means of distinguishing, however, between the flood-alluvium of rivers and these lacustrine deposits seems to be a desideratum, and as the result of the examination of a large number of sections of river-silt in the magnificent exposures opened in the excavation

¹ *Geogr. Journ.* vol. iv (1894) p. 237.

² *Monogr. U.S. Geol. Surv.* vol. xxv (1896).

of the Manchester Ship-Canal, and the comparison of the materials with the Warps of Yorkshire, I have obtained, as I believe, a means of discrimination.

Flood-alluvia are cast down upon meadows through which the streams meander, and consequently the area occupied by them presents very little relief: hence upon our geological maps we find these flat meadows marked as alluvium, the boundaries following the feature against which the deposits halt. The flood-alluvium is cast upon a surface well covered with herbage, and consequently any bedding which it may display is irregular, and is liable to obliteration by penetration of roots and by other agencies.

Take, now, the case of a lacustrine deposit—it is dropped over the whole floor of the lake, which may have a greatly diversified and undulating surface, upon which the mud will lie as a nearly uniform mantle. There may be absolutely no vegetation upon the lake-bottom, either to produce any original irregularity, or to efface eventually the laminations; consequently such limnal muds may be expected frequently to display close and regular laminations, which, being parallel to the subjacent surface, may be highly inclined.

Fig. 1.—Section at Danby Brick-and-Tile Works.

Anyone who has studied the ancient Warps of Yorkshire will know how generally these characters, which I have regarded as indicative of lacustrine origin, are present. The late Canon Atkinson in his fascinating book, 'Forty Years in a Moorland Parish,' describes a sort of prophetic vision of a great lake in Upper Eskdale (where, as I shall show in the sequel, a glacier-lake of large dimensions probably existed); and he justifies his vaticinations by one piece of geological evidence, the exceedingly close and regular laminations of the Warp-clays of the district. The exposure to which he refers certainly furnishes me with my clearest and best

illustration. This section is exposed in a pit at Danby Brick-and-Tile Works (fig. 1, p. 478).

The red and blue clays display no visible bedding, but the leaf-clay (that to which Canon Atkinson referred) contains interlaminae of exceedingly fine sand. He mentions between 24 and 30 alternations in 4 inches, but this is an underestimate. A specimen which I took shows 24 coarser layers to the inch, and each of these includes about 8 finer laminae, making in all about 200 laminae to the inch. The laminations at one side of the section show a high north-easterly dip. Occasional stones, flat, and 'as large as a tile,' are said to occur. One such large stone yielded, when broken up, about half a cartload of fragments. The leaf-clay unfortunately has not been penetrated by the excavation; and at the Tile-Works in Little Fryup, a boring was put down 60 feet in laminated clay without reaching the Lias.¹

A section (fig. 2) in the brickyards at Dringhouses, west of York, gives an instructive view of similar beds with the underlying deposits. The section was drawn in my notebook in 1895, before I had recognized its significance. The brickyard is situated between the reticulated northern series of morainic hills, and the single sharply-defined moraine-ridge that is so conspicuous a feature for 4 or 5 miles to the westward of York.

Fig. 2.—Section in the brickyard at Dringhouses, York.

[1=Gravel; 2=Laminated clay (Warp).]

My notes state that the laminations are parallel to the surface of the gravel, to the height of 10 or 12 feet above it. A visit paid to the section a few days before the reading of this paper, showed that the gravel-mound had been cut away to the floor-level of the pit, but the steeply-inclined laminae of the Warp could be observed dipping into the face of the section.

¹ Mem. Geol. Surv. 'Eskdale & Rosedale' 1885, p. 51. It is important to observe that this is mapped as Boulder-Clay, no doubt because of the absence of alluvial features.

(4) **Overflow-channels.**—The overflows of glacier-lakes have attracted but little attention in this country. Those of the Glen-Roy Lakes, so far as can be gathered from descriptions, present no marked features of eroded channels, but are merely scoured cols which have been swept fairly clean by the effluents of the lakes. Nevertheless I think that one or two of them show features of particular interest, judging by the maps and the behaviour of some streams related to them. Dugald Bell appears to have been the first geologist to have recognized that an ancient lake might be postulated from its overflow with as great certainty as by any other sign; and as I have already remarked, he described¹ a lake-overflow at Dalry, enforcing his conclusion by the evidence of floor-deposits. Prof. James Geikie made similar observations quite independently.²

In America such phenomena are among the regular data of glacialists. The most noteworthy in the whole continent is no doubt the great overflow of Lake Agassiz, known as the Warren River, which is described at length by Mr. Upham in his monograph already cited. Mr. Upham, in allusion to these phenomena, says that he regards them as evidences of glacial lakes 'the most invariably recognizable and the most definite in their testimony,' an opinion which I most cordially endorse.

As these features are but little known to British geologists, and my experience of them extends to over three hundred examples, chiefly in Yorkshire, but also in Northumberland, Westmoreland, Lancashire, Cheshire, and Lincolnshire, it seems desirable that I should describe the general characters with some care, the more so as I have placed my chief reliance upon them in the identification of the series of lakes which form the subject of this paper.

When an ice-sheet or glacier obstructs the drainage of a country, the water is impounded so as to form a lake, which will find an escape either through, or over, the ice; or, by overflowing, by some col or spur in the surrounding watershed.

In the former case, the evidence remaining to the geologist after the disappearance of the glacier will consist solely of beaches, deltas, and lacustrine deposits; but in the latter, and in such a country as ours, the more common case, of overflow across a col, or spur, the water proceeds to cut for itself a channel. The deepening of this channel may be swift or slow according to local conditions. Upon the withdrawal of the ice, it may be that a morainic obstruction may be left across the valley of such a height that a lake may persist for a considerable period, until, in fact, the overflow has cut far enough down to drain it, and then remains as the permanent course of the drainage. Or the overflow-channel may have cut

¹ Trans. Geol. Soc. Glasgow, vol. iv (1874) p. 66.

² 'Great Ice Age' 2nd ed. (1877) p. 146. I ought, however, to point out that a consideration of the peculiar conditions prevailing in the Clyde area at the close of the Glacial Period seems to forbid the ascription of any considerable part of the excavation of the valley in question to a lake-overflow of the same date as the deposits.

down during the persistence of the ice-barrier; and when this happens, we find the events recorded in the form of a river-gorge of a breadth disproportionately small as compared with the magnitude of the stream, and an abandoned valley of a normal form obstructed near the deviation by the moraine.

Such a gorge is that of the River Nidd near Knaresborough, described by me in a paper presented to the British Association in 1896.¹ In other cases, it may happen that upon the retreat of the obstructing ice the drainage may be resumed upon the original lines, though perhaps over a raised floor of Drift. When this is the case, the temporary overflow-channel will be abandoned, and will thereafter carry only such small amount of drainage as belongs to its own very limited catchment, sometimes even none at all.

Here now are two distinct types of anomaly in valleys both bearing the cañon-like aspect that tells of rapid erosion: but in one case the valley is narrow out of proportion to the stream that occupies it; in the other the stream, if stream there be, is disproportionately small for the valley. In every district in which I have found these evidences, both types occur; often, where a chain of parallel lakes existed draining one into another, the two types of valleys occur in rough alternation, as in the country between the Ure and the Wharfe from Hackfall to Tadcaster.

The anomalous valleys which at present constitute the main drainage-channels of Cleveland, present no special features to which I need devote attention here. Their recognition is easy, and their characters simple; but 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 appeal to me as perhaps the most impressive memorials of the Ice-Age that our country contains.

IV. GENERAL CHARACTER OF THE ABANDONED CHANNELS.

These valleys conform to four principal types in regard to position.

(1) Direct overflows.—Those which trench the main watershed of a country so that the overflow is directly away from the ice—these may for convenience of reference be termed direct overflows. The finest example in the Cleveland area is Newton Dale. Direct overflows are usually found to trench only the lowest cols of a given watershed, except where the obstructing ice has approached very near to the watershed. They generally occur singly, one overflow serving for the drainage of a considerable area of the iceward side of the country; but when the watershed is very uniform in height, and the ice has at one stage actually surmounted it, then several parallel overflows may be developed out of the gutters which are trenched in the outer slope by water

¹ Rep. Brit. Assoc. 1896 (Liverpool) p. 802.

flowing off the ice itself. The overflows, four in number, which cut through the Northern Cleveland watershed above the village of Egton are typical of this arrangement.

(2) Severed spurs.—I have applied this name to those cases where the drainage of minor valleys has been carried across spurs of a main watershed. Such cases arise where the ice-front, being opposed to a main watershed, has impounded the waters of valleys descending towards it at an elevation such that a direct overflow is not available. The waters of the lake then discharge, either across a depression of the spur, or by a channel cut on its outer face along the edge of the ice. The former case differs in no essentials from a direct overflow, but the latter constitutes my third type.

(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. When considering the evidence of any direct overflow, I have only in rare instances admitted the validity of the proof where no related severed spurs could be found to corroborate the available data.

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 throw some intermediate channel out of operation, while its neighbours, above and below, continue to fulfil their functions and to cut lower.

Upon a comparison of levels, we find that the intermediate channel is at a higher altitude than its neighbour up stream. The same statement may apply to a marginal overflow that has an ice-wall in the middle part of its course. A retreat of the ice up to this point may allow of a 'lateral escape' being formed, and the upper segment of the overflow may cut deeper than the lower. An example of this is afforded by the Murk-Mire-Moor channel.

A retreat from the upstream segment of a marginal overflow will produce a 'lateral intake.'

The other kind of serial development I have termed a parallel or successive 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. This is beautifully illustrated by the interesting little pair of valleys on Moorsholm Rigg which I have termed 'the Double,' and even better by the splendid series cutting the hills above Hayburn Wike.

Sometimes a parallel sequence may be observed, in which the fall of the channels is in opposite directions in successive valleys of the sequence. This is found in cases where there are two main overflows at opposite ends of an aligned sequence, or where ice-streams from opposite quarters have successively invaded an area.

The clearest case of the latter kind known to me, I observed in the Cheviots between the valley of the Breamish and Roddam Dean¹; but in Cleveland the former phenomenon is to be well seen near Stanghow, and in a most perplexing development between two main escapes north and south of Scarborough.

(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. Two admirable examples are known to me in Cleveland, one detaching the hill known as Stony Ruck near Freeborough, and the other the Sunny Brake Valley near Glaisdale (see fig. 20, p. 530).

I may now consider some peculiarities of form displayed by these valleys.

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 (to the depth, in some instances, of more than 20 feet), and this produces often 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,

¹ P. F. Kendall & H. B. Muff, *Geol. Mag.* 1901, p. 513.

where unmodified by subsequent stream-action, possess very broad flat floors. These features are exhibited in their highest perfection in those cases where the valleys have been excavated in very soft rocks, such as the shales of the Lower Estuarine Series: they indicate rapid cutting by a large stream.

The same deduction may be drawn from the character of the 'meanders.' In a large valley of normal drainage, the sinuosities of the valley bear little or no direct relation to the meanderings of the stream, and this independence is the more conspicuous the flatter the floor of the valley is. It is only the banks of the stream that show such a relation, the well-known one that the steep bank is on the outside of a bend, while a gently shelving bank is on the inside. The reason for this is obvious, and need not be enlarged upon. Now, in the valleys which I am describing, the glacial stream fitted the valley so closely that the valley-walls were also the banks and follow the rule just cited.

In each meander of one of these valleys the outer curve is steep, sometimes precipitous, while the inner curve has a more gentle slope. These features are nowhere more beautifully displayed than in the upper portion of Newton Dale above Raindale Mill. Here, for several miles, the railway from Pickering to Whitby runs through a superb cañon having a depth of 300 or 400 feet, and occupied through a part of the distance by a small stream, the Pickering Beck. The outsides of the meanders here are in many places so precipitous as to be unscalable.

It is a noteworthy circumstance, that at Raindale Mill a tributary stream of large size belonging to the normal drainage enters Newton Dale, and below this point the valley takes a nearly rectilinear course without meanders. This may imply that the valley above this confluence has been produced mainly by the lake-overflow, while below it a pre-existing valley of considerable size has simply been deepened and perhaps broadened, its main lines being preserved. The neighbouring normal drainage-valleys on each side of Newton Dale exhibit no such features as the upper part of that valley.

The head of an overflow-valley generally shows some very characteristic features, which may be well studied by the aid of contoured maps where the contour-lines are drawn every 25 feet.¹ As a rule, in ascending such a valley, the sky presently shows through the clear-cut notch of the intake, and on the map successive loops of the lower contours are replaced by lines of the higher elevations passing right through and round the hillsides. On the lakeward

¹ I would here remark that the extremely detailed work which I have been able to do in Yorkshire has been rendered possible only by the very perfect 6-inch contoured maps of the Ordnance Survey. In this favoured county the contours are drawn every 25 feet, whereas in such counties as Northumberland, Cheshire, Westmoreland, and Norfolk, they are drawn at each 100 feet. In comparatively flat Norfolk there are doubtless sheets without a single contour-line. The counties that I have mentioned can never be satisfactorily studied by glacialists, unless a new survey be made.

side the lower contours of a hillside pass unindented across below the intake (see Lady-Bridge Slack, Pl. XXII).

The outfall often displays analogous characteristics, and a valley will open out inconsequently upon a steep hillside. The level at which the debouchure takes place is approximately the level of a lake, but it is often rendered obscure by subsequent cutting on the part of a small stream; the Murk-Mire-Moor and Ringing Keld valleys are, however, practically intact. The intake frequently presents modifications of interest, which corroborate the views here set forth regarding their origin. The head of the valley often makes a sharp turn towards the quarter whence the main overflow took place. For example, the head of Ewe-Crag Slack looks directly westward towards the chain of lakes drained by it, although the main valley runs nearly due north and south. The same feature was observed by Mr. Muff and myself in an overflow at North Bierly, Bradford.

In other cases, a marginal shelf and scarp runs up to the intake, produced, evidently, by the ice being thrust forward against the

Fig. 3.—*Map of the Mürjelen See.*

[Scale: 1 : 50,000.]

lake-outflow, just in the same way that the Aletsch Glacier swells forward against the Eggischhorn (fig. 3).

This feature is shown in a very marked manner by the intake of the Moss-Swang Valley at Lords Seat.

At the outfall there is at times to be seen a mass of gravel constituting the delta. The materials usually consist of a preponderance of the materials eroded from the valley, where these are of a sufficiently durable character to form pebbles, together with erratics washed over from the ice-front. Sometimes these deltas are of very large size, and are generally proportioned to

the magnitude and duration of the overflow. The largest that I have seen in the Cleveland area are those of Newton Dale, Ewe-Crag Beck, Tranmire (or Stonegate), and Forge Valley.

In connection with this I may mention a minor though interesting feature of outfalls, their bifurcation. Two quite distinct causes must be assigned. In an example in Cleveland at Smeathorne, a

marginal overflow has bifurcated in consequence of a slight recession of the ice permitting the water which was flowing in contact with it along a hillslope to take a lower course. The other cause of dichotomy at the outfall I have observed only in the Cheviots. The case is that of a pair of lakes, with an intervening spur terminated near the ice-margin by a bold knob. The spur is cut behind the knob by a deep overflow-channel, at the outfall of which a great gravel-delta has been thrown down. The outlet was at first probably over the convex fan of deltaic material, but with a shrinkage of the ice and corresponding lowering of the lake-level, the flow took place along each side of the delta; then a further recession of the ice allowed the lower lake to drain off through a marginal channel, and this gave an advantage to the outfall nearest to the ice, which therefore became the sole outlet. These features are precisely repeated in two adjacent valleys, Monday Cleugh and the gorge behind Hambleton: the marginal outflows can be seen, and I therefore feel some confidence in the explanation.¹

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 (50 or more) above the functional channel. Such a case is to be seen at Brown Rigg, near Robin Hood's Bay. 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. Evan-Howe Slack, a quarter of a mile from Brown Rigg (see Pl. XXVI), and the channel which isolates Castle Rigg, in the Moss-Swang overflow near Goathland (see fig. 8, p. 510, & Pl. XXII) present examples of this type.

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.

Newton Dale, which has served so often as an illustration, may

¹ Details of these will be found in a paper, by Mr. H. B. Muff and the author, read to the Edinburgh Geological Society on March 20th, 1902.

conveniently be taken as typical of this feature also. Above Raindale Mill several tributary streams come in, but they are all very short and of small volume, and it is clear that the main valley could not have been produced by confluence of such elements; moreover, they enter the main valley with a plunging slope, almost every one producing waterfalls, and sometimes sheer drops. They come out on the flat moor-tops 300 feet above the main valley, a few hundred yards above the confluence. It is right to point out that, for a considerable distance, the moor is a plateau corresponding with the top of a hard bed of rock (Kellaways), and therefore the small streams would find it difficult to cut through; but this condition is not general, while the peculiarity of the lateral valleys is.

An alternative possibility which I have had also to keep constantly in view is, that in limestone-rocks streamless valleys may occur which have been produced by normal drainage during the Glacial Period (when all rocks were frozen, and therefore impervious to water), whereas now no streams are possible in consequence of the porosity of the limestone. Such valleys I know well; they abound on the Chalk Wolds, but their characters are quite different from those of Glacial overflows: they do not cut watersheds.

V. PRE-GLACIAL LEVEL OF THE LAND.

The pre-Glacial level of Yorkshire appears to have been considerably above its present elevation, for borings and mine-workings have proved in many places Drift-filled hollows descending far below sea-level; yet in no case has anything like a sea-bottom or marine deposit been encountered, except in Holderness, to which reference will be made later.

Borings close to the coast prove nothing very definitely, as we do not know the exact form of the pre-Glacial coastline; so that the borings near the mouth of the Tees, stated by Mr. Barrow¹ to prove Drift down to 90 feet below sea-level, do not yield much enlightenment on this particular point; and the borehole at the Grand Hotel, Scarborough, which proved the presence of Boulder-Clay to a depth of 100 feet below sea-level,² may well have been outside the pre-Glacial shore-line. Right down the great valley from Newcastle to Doncaster, however, there is abundant evidence of a convincing kind. The great wash along the Leam depression described by Nicholas Wood & E. F. Boyd³ is an old river-valley, Drift-filled at present, which at Gateshead is 140 feet below sea-level.

From the Tees southward, borings indicate a great depth of Drift, until a line connecting Northallerton and Bedale is reached. Here the Drift is shown by boreholes at Northallerton, Thornton-le-Moor, Leeming Lane, and other places to be very thin; and, as it

¹ Mem. Geol. Surv. 'North Cleveland' 1888, p. 68.

² Mem. Geol. Surv. 'Oolitic & Cret. Rocks South of Scarborough' 1880, p. 31.

³ Trans. N. of Engl. Inst. Min. Eng. vol. xiii (1863-64) p. 69.

thickens again to the southward with a falling surface, it is clear that an old watershed extends across the valley.

In the neighbourhood of York, the Drift has in many places been proved to rest upon a rock-floor about 50 feet below sea-level: southward it descends lower still, namely, to 74 feet at Cawood, and in a boring at Barnby Dun, near Doncaster, I saw Drift-clay being brought up from a depth of about 170 feet below Ordnance-datum.¹

In the Vale of Pickering, according to Mr. Fox-Strangways,² the superficial deposits reach a thickness of 107 feet, and

'if the superficial deposits were removed, the sea would again enter this valley to beyond Malton.' (*Loc. cit.* footnote.)

The foregoing facts, especially those regarding the country about York and the Vale of Pickering, show that in pre-Glacial times the land must have stood very much above its present level, the Barnby-Dun boring indicating a minimum of probably 170 feet; but there is a most perplexing complication introduced by the evidence obtainable in Holderness, to which I purpose reverting on some future occasion.

The researches of Mr. Lamplugh have shown that the ancient coastline south of Flamborough Head swept in behind (that is, west and south-west of) Bridlington, and he has admirably described the contents of an old sea-beach, clearly of pre-Glacial age, as it is covered by the oldest Glacial deposits of the district, which lies at the foot of a buried seaworn cliff at Sewerby. This cliff can be traced by borings and other excavations round to the Humber at Hessel; and the whole district of Holderness consists of Glacial deposits resting upon an old plain of marine denudation extending out from the foot of the cliff. The beach is practically at the level of the existing beach.³ What relation in time this level of the land bore to the period of elevation, when the deep valleys were excavated, it is not easy to ascertain: but the Sewerby-beach stage seems to have been a long one, judging by the magnitude of the denuded floor under Holderness. The excavation of the broad Vale of York must also have been a very slow operation.

No marine or estuarine fossils have been discovered in the superficial deposits of either the Vale of York or that of Pickering, but near Speeton an estuarine deposit of pre-Glacial or early Glacial age occurs at an altitude of 90 feet above sea-level.⁴ This, however, is outside the Vale of Pickering, or at least on the seaward face of the Chalk-escarpment which swings round out of the Vale. Moreover, if its present position is due to any general earth-movement, and

¹ I have prepared a map showing the depth of the rock-floor from Seaton Carew to Barnby Dun, which will be published in the Proceedings of the Yorks. Geological & Polytechnic Society.

² Mem. Geol. Surv. 'Jurassic Rocks of Britain' vol. i (1892) p. 432.

³ The maximum difference of level does not exceed 5 feet. See G. W. Lamplugh, etc. 'Report on an Ancient Sea-beach' Rep. Brit. Assoc. 1888 (Bath) p. 336.

⁴ See G. W. Lamplugh, 'Drifts of Flamborough Head' Quart. Journ. Geol. Soc. vol. xlvii (1891) p. 384.

not, as Mr. Lamplugh thinks, to a local deformation, it proves a lower land-level at that period, not a higher.

The blown-sand and landwash resting on the Sewerby beach do not necessarily imply even a temporary elevation, of however small an amount ; for, as the obstruction upon the eastern coast of Britain of the great Scandinavian ice-sheet would be exercised progressively from north to south, and it is probable that the Straits of Dover had not been opened at the beginning of the Glacial Period, the narrowing strait to the northward would admit so little tidal water that the North Sea would become practically tideless, and the highest beaches (namely the ' storm-beach ' and springtide beach) would be abandoned by the sea. I think it quite probable that the blown-sand and landwash of the Sewerby section represent this phase, which must have intervened between the abandonment of the beach and the onset of the ice that deposited the Basement Boulder-Clay. Briefly, the evidence of the Vale of Pickering and the Vale of York indicates a long period of pre-Glacial elevation ; while the evidence of the Sewerby beach and cliff, with the wide plain of marine denudation which confronts them, shows very clearly that for a long period of time (pre-Glacial or early Glacial) the land-level was practically identical with that of to-day.

How these apparently conflicting results are to be reconciled I cannot undertake to suggest, beyond saying that the different levels were probably successive.

VI. GLACIAL DEPOSITS AND GLACIATION OF THE CLEVELAND AREA.

The Glacial deposits which fringe the Jurassic hill-country of Yorkshire, and penetrate at a few points into the interior of the system, present few features special to the region, save in the matter of distribution and the nature of the included erratics.

Most writers on the subject have recognized a threefold division of the Drift, namely :—

Upper Boulder-Clay ;
Middle Sands and Gravels ; and
Lower Boulder-Clay.

Few sections exist which show the three divisions superposed, and it appears to be mainly by its relation to a bed of sand or gravel—assumed to be the middle member of the series—that a mass of Boulder-Clay can be pronounced to belong to the Upper or Lower.

In the Geological Survey Memoir on the country round Northallerton, Mr. Fox-Strangways speaks of the 'reddish Upper Boulder-Clay,' and later of the 'Boulder-Clay,' maintaining throughout this region 'its usual character of a stiff clay having a dark colour when unweathered.' He further remarks that 'foreign rocks occur principally in the lower Boulder-Clay, the upper clay is almost stoneless.' It may be gathered from this, that there are two beds of Boulder-Clay—a lower, which is blue, and contains many boulders ; and an upper Boulder-Clay, which is red, and

almost destitute of included stones. This distinction has not been noted in the area to the south, but Mr. Barrow found that in the Northern Cleveland area the Upper Boulder-Clay was of the same character; while the lower bed differed from that described by Mr. Fox-Strangways only in being of a dark chocolate-colour, varying at Whitby to reddish purple. The same divisions, similarly characterized, are mentioned in the Geological Survey Memoirs on Eskdale & Rosedale, and on the country between Whitby and Scarborough, but in that on the country south of Scarborough no attempt at such a classification is made.

At Flamborough Head and in Holderness, however, the two Boulder-Clays appear with their normal characteristics. I may here remark that a relatively stoneless Upper Boulder-Clay has been recognized by Hull, Mackintosh, and others in Lancashire and Cheshire; but I am not convinced that the distinction is a constant and valid one. The Middle Sands and Gravels form a very unsatisfactory division; and while in some sections they appear to be entirely absent, in others there are several beds intercalated between successive sheets of Boulder-Clay (as, for example, in a boring at Stokesley).

Regarding the relative altitudes which these subdivisions are said to attain upon the hills, there appears to be complete accord among the officers of the Geological Survey. Both Mr. Fox-Strangways and Mr. Barrow remark that the Lower Boulder-Clay is found at much greater altitudes than the Upper Clay, and that the 'Middle Sands and Gravels range still higher.'

Apart from the general statement that foreign stones are more abundant in the Lower than in the Upper Clay, little has been recorded regarding any differences between the erratics contained in the Boulder-Clays. However, information of value has been supplied respecting the boulders contained in the Lower Clay at Whitby. They include Carboniferous Limestone, Magnesian Limestone, Yoredale cherts and sandstones and Shap Granite, along with patches of Lower Liassic shale. These records are of great importance, as they enable us to say that at the time when the oldest Drift-deposits of the district were being accumulated, a transport of erratics from the westward or north-westward had already set in. My own notes record the following stones from the 'Middle Sands and Gravels' in the same cliff:—

Jurassic and other sandstones, Magnesian Limestone, Carboniferous Limestone (not very abundant), basalt, greywacke sandstone and conglomerate ('sparagmite'?), jasper, alum-shale (a large block), *Gryphæa incurva*, and a ball of red Boulder-Clay.

This assemblage is very similar to that in the Lower Clay. Taking the whole of the erratics in the district without particularizing the beds in which they have been found, the following groups may be recognized:—

1. SEDIMENTARY ROCKS.

'Greywacke' sandstones and conglomerates; jasper-pebbles; Carboniferous basement-conglomerate (Roman-Fell type); Carboniferous limestones, cherts, grits, and sandstone; Brockram (Permian); red

sandstone (perhaps Triassic); grains of red marl (perhaps Triassic); Liassic rocks and fossils representing every division; Jurassic sandstones and limestones; Chalk and flints (generally black, and not of the indigenous Yorkshire type).

2. METAMORPHIC ROCKS.

Gneisses and schists.

3. IGNEOUS ROCKS.

Granites from the South-west of Scotland (Criffel, etc.); holocrystalline rocks (including Shap Granite), lavas, and ashes from the northern and eastern portions of the Lake District and the Vale of Eden; the Whin Sill, and Cleveland Dyke; porphyrites from the Cheviot Hills; elæolite-syenite, laurvigite, and rhomb-porphyrity from the Christiania Fjord. Quartz-porphyrity, granites, etc., the place of origin of which is at present doubtful.

The rocks may be grouped, according to the probable or ascertained place of origin, in the following manner:—

- I. South-western Scotland.
Criffel Granite.
- II. The Lake District and the Vale of Eden.
Shap Granite, lavas and ashes of the Borrowdale Series, Brockram, Carboniferous conglomerate, vein-quartz.
- III. Teesdale or other valleys of the northern part of the Pennine Range.
Carboniferous limestones, grits, sandstones, and cherts.
- IV. South-eastern Scotland (Valley of the Tweed) and Cheviot Hills.
'Greywacke' sandstones and conglomerates, jasper, porphyrites.
- V. Eastern Durham.
Magnesian Limestone (botryoidal type of Roker, near Sunderland).
- VI. Christiania region.
Rhomb-porphyrity, laurvigite, elæolite-syenite, and perhaps some of the 'greywacke' sandstones and conglomerates ('sparagmite'), many metamorphic rocks.
- VII. Gulf of Bothnia.
Post-Archæan granite of Ångermanland, and probably some quartz-porphyrity.
- VIII. Denmark, or bed of the North Sea.
Black flints.

These series may be arranged again in three sets, to indicate the possible routes by which they travelled. Series I, II, & III may well have travelled together in a movement from the Irish Sea by way of the Solway Firth, the Vale of Eden, Stainmoor Pass, and the Tees, probably with a loop-line *via* the Tyne. This may be termed the Western Group.

Series IV and V have probably travelled in company, as the coast of Durham lies immediately in the path from the Cheviots to the Cleveland area. It is possible that some of the Carboniferous rocks and the Whin Sill may have come by this route from Northumberland; but, except the Cheviot porphyrites, no distinctive Northumbrian rock such as the 'Pea-Post' (*Saccamina*-limestone) has yet been found in Yorkshire. It should, however, be pointed out that the Pea-Post is generally an extremely friable rock, unlikely to

withstand much rough usage in transport. This may be termed the Northern Group.

Series VI, VII, & VIII, constitute a natural Eastern Group.

The Jurassic rocks and Cleveland Dyke are native to the Cleveland Hills. Mr. Barrow has noted several cases, in which large masses of Lias have been lifted and deposited at a higher level than the adjacent outcrops.

Reference has already been made to the relative distribution in altitude of the different members of the Drift Series. I may now briefly describe the distribution of the Drift as a whole.

The Drift-deposits, including in the term all deposits of Glacial age without reference to the mode of their formation, completely surround the Cleveland area, and extend through the two valleys, the Vale of Pickering and Eskdale, which run in a westerly to easterly direction across the Jurassic outcrop; but, except on the north, they extend only a short distance into the hill-country, and the great valleys which trench the Jurassic dome on the south side of the watershed, as well as the dome itself, are entirely Driftless.

Regarding the northern slopes of the Cleveland area, Mr. Barrow remarks, 'The Drift becomes very thin at 600 feet above sea-level, and disappears altogether above 850 feet.'¹ My own observations in the main confirm those of Mr. Barrow, but as, throughout this work, I have freely used a hand boring-tackle, I have in a few instances been able to rectify his lines in unimportant details of boundaries.

Commencing at the western end of the great Cleveland escarpment above Ingleby Arnecliff, the Drift is found to run up the slopes to an altitude of about 400 feet; and, though this appears to be the general level to which the continuous sheet of Drift attains along the steep face of the escarpment, in embayments, such as Scugdale, it extends to over 700 feet, and on a few spurs, as at Busby Wood, to over 800 feet, and a similar elevation is reached near the ascent to Chap Gate. Beyond this point the levels fluctuate considerably, and the maximum is attained on the Lockwood Hills, where a spread of gravel forms a capping at 867 feet. Farther eastward, the boundary varies slightly above and below 800 feet, until at Robin Hood's Butt the watershed falls at one col to the Drift-level, 760 feet. From Stonegate eastward, the Drift crosses the watershed in an almost continuous sheet as far as Whitby, interrupted however by Kempston Rigg, which forms a narrow Driftless strip at altitudes above 800 feet.

While the actual Drift-deposits are thus limited to levels not exceeding 867 feet, there is a sporadic scattering of small erratics reaching at three or four places upon the brow of the escarpment to higher levels: thus at Carlton Bank, pebbles of foreign rocks were found up to 1000 feet. Similar phenomena have been observed in other parts of the district: for example, scattered pebbles, mainly of white quartz, were noticed by the officers of the Geological Survey

¹ Mem. Geol. Surv. 'North Cleveland' 1888, p. 6

on High Moor near Peak at 850 feet, and I have found in the same district a thin deposit of gravel at Green Dike at 825 feet, which yielded pebbles of granite, quartz-porphyr, porphyrite, and flint. I do not think that in all cases these scattered pebbles can be accepted as evidence of a wider extension of actual Drift-deposits. Still less do I consider that it would be safe to infer that they necessarily imply the invasion of the area by ice to so great an altitude.

Along the strip of country from Robin Hood's Bay to Seamer, the maximum altitude reached by the Drift falls from about 700 feet at Gate Hills, and 825 near Pye Rigg, to 600 feet on Scarborough Racecourse; but the general level between the two points declines fairly steadily from 700 down to about 400 feet. Some authors have experienced a difficulty in understanding how deposits laid down along the edge of a sheet of land-ice should show such variations as these, but it should be observed that higher grounds upon which such deposits could be laid do not exist continuously along a line connecting the two extreme points. At the southern end, it is noticeable that the Drift simply touches the front of the moor, and does not extend down its gentle westerly slope. Along this strip of seaboard, the Drift, except for a small patch in the bottom of the valley near Hackness, nowhere extends more than 4 miles from the coast, and the hill-country within is quite destitute of Drift.

Drift-deposits in the Vale of Pickering do not attain a greater altitude than about 350 feet. The patches of gravel and of Boulder-Clay at the western end of the Vale are worthy of a more extended study than I could devote to them; but Mr. Fox-Strangways records that the patch of Boulder-Clay near Thornton Dale contains local rocks exclusively, and I have recently examined two areas mapped as Boulder-Clay near Helmsley, at the Acres and at Sprotten respectively, and such scanty traces as I could find yielded local rocks solely.

The Drift-deposits along the escarpments overlooking the Vale of York, though outside the area dealt with in this communication, may nevertheless be mentioned, as they have an important bearing upon the mode of origin of the Glacial deposits and features herein to be described.

Mr. Fox-Strangways says,¹

'Taken as a whole, the Glacial deposits never rise much above the 600-foot contour-line, and only attain this elevation along the northern escarpment of the Oolites; in the south they are not usually more than 400 feet above sea-level, except at Oulston, where the gravels rise to nearly the 500-foot contour.'

The Drift extends for a long distance to the southward, and, excluding some small patches marked as Boulder-Clay and gravel along the edge of the hills, it may be said to terminate in the two splendid moraines at York and Eserick respectively.² The summit-

¹ Mem. Geol. Surv. 'Northallerton & Thirsk' 1886, p. 53.

² Carvill Lewis, Rep. Brit. Assoc. 1887 (Manchester) p. 692, & 'Glac. Geol. of Gt. Britain & Ireland' 1894, p. 188; P. F. Kendall, Proc. Yorks. Geol. & Polyt. Soc. n. s. vol. xii (1893) p. 306.

altitude of the highest of these moraines at Bilbrough is rather over 150 feet above sea-level.

Glacial Striæ.

Down to the time when the geological maps and memoirs of the district were published, no Glacial striæ upon the bed-rock had been discovered; but Mr. Barrow, in his memoir on North Cleveland, stated that at Hob Hill, near Saltburn, when the Drift was cleared away, 'the Ironstone was found to be deeply grooved, the direction of these hollows running roughly north-west and south-east.'¹ The Drift here appears to have been recognized by him as Lower Boulder-Clay, an important fact. Mr. Barrow also mentioned that, 'as a rule, where the clay is thin it is so largely made up of the underlying rock, or the rocks a little to the west' (*op. cit.* p. 65) etc. Since that time, the geologists of the East Riding have taken up the study of the Glacial deposits with great earnestness, and the following observations of striated surfaces have been recorded:—

Filey, Carr Naze (south side). G. W. Lamplugh. N. 20° E.

Do. Do. (north side). J. W. Stather. N. 24° E.

Bayness (north of Robin Hood's Bay). H. B. Muff & T. Sheppard. N.

Sandsend, near Whitby. J. W. Stather. N. 35° W.

Roker, near Sunderland. P. F. Kendall. E.N.E.

Reference should also be made to the striations observed in the coast-region of Northumberland, as they bear directly upon many of the problems relating to the glaciation of Yorkshire.

The distribution of local materials in the Drift of the area under consideration is very significant, as Mr. Barrow has shown for the area north and west of Whitby. South of that town, I have observed the frequent occurrence along the coast of masses of Jurassic rock to the south of their native outcrop; but I have heard of only a single example that might be interpreted as indicating movement in the opposite direction, namely, Mr. J. W. Stather's record of blocks of Chalk at Scalby Mills, near Scarborough.²

Occurrence of Shells in the Drift.

Shells, mostly fragmentary, have been recorded from the Drift-deposits of various localities in the area under notice, except the western end of the Vale of Pickering. Mr. Fox-Strangways, speaking of the gravel which fringes the great escarpment to the east of Ingleby Arncliffe and runs up the dales opening off it, alludes to 'hinges of *Tellina balthica* being very plentiful in this gravel.'³

Mr. Barrow, in the North Cleveland Memoir, mentions the occurrence of the same shell at Rye Hill near Great Ayton (I also have found several fragmentary shells at this place); at Stanghow Moor, in sand resting on Lower Boulder-Clay (at an altitude of about 800 feet); and at Whitby, in Lower Boulder-Clay. In the Eskdale

¹ Mem. Geol. Surv. 'North Cleveland' 1888, p. 66.

² Rep. Brit. Assoc. 1898 (Bristol) p. 554.

³ Mem. Geol. Surv. 'Country around Northallerton' 1886, p. 54.

& Rosedale Memoir the species is recorded in Eskdale at Egton, at Far Carr Wood, and at a pit near Egton Church with other shells, and again in the Lealholm moraine (see p. 506). In the Memoir on the country between Whitby and Scarborough, *Tellina balthica* is recorded as occurring in the Middle Sands at Robin Hood's Bay; and in the Memoir on the country to the south of Scarborough, it is stated that great numbers of shell-fragments occur in gravels on the north side of the Vale of Pickering, about Wykeham and Ayton.

VII. THE ICE-SHEETS.

It will greatly facilitate the line of argument which I propose to develop in the following sections, if I state at the outset the conclusions to which my studies have led me regarding the course and distribution of the ice-currents that operated about the margins and, to some extent, over the ridges of the Cleveland area. I may first remark, that I have been unable to detect any signs of the presence of the sea in the area at any time during the Glacial Period; and the occurrence of fragmentary and a few whole shells I ascribe 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 shells. I have elsewhere stated pretty fully the reasons which have weighed with me in arriving at this conclusion, and it is satisfactory to find that many of the *a priori* objections urged against the possibility of glacier-ice picking up, transporting, and redepositing marine shells derived from deposits over which it has passed, have been dissipated in a decisive way by the observations of Profs. Garwood & Gregory upon the Ivory-Gate Glacier.¹ The same observers also proved in a conclusive manner that shells and other materials picked up by a glacier could be transported to a higher level than the bed from which they were obtained.

The principal facts with which I started out were—firstly, the occurrence of three groups of erratics derived respectively from the west, the north, and the east; secondly, the distribution of the Drift as a continuous sheet on the west, north, and east of the Cleveland Hills, and not in the central part, except in the Esk Valley; and, thirdly, the striations and the nature of the deposits.

I will consider the western group first.

It has long been known, mainly thanks to the accurate researches of Mr. J. G. Goodchild, Mr. W. Gunn, and the late Prof. Carvill Lewis, that at one stage of the glaciation of England, so great a condition of congestion existed in the Irish-Sea basin, that a great volume of ice bore in upon the Solway, and being joined on the one hand by ice from the Southern Uplands of Scotland, and on the other by that from the Lake District, it filled the Vale of Eden to overflowing. One immense stream swept over the Tyne watershed and invaded Northumberland, while at the other end of the Crossfell

¹ Quart. Journ. Geol. Soc. vol. liv (1898) pp. 205, 206, 219, etc.

Range a great overflow took place by the Pass of Stainmoor, at altitudes ranging from 1435 feet (the lower pass) to 1800 near Roman Fell. This latter glacier entered Teesdale just below Middleton, where (as I am informed by Mr. Derryhouse) it was joined by a native glacier having its source in Upper Teesdale. It was charged with igneous rocks from the Lake District, most notable of which is the Shap Granite. This glacier made its way down into the low grounds, where it seems to have deployed considerably, and it reached the sea-coast, which was probably not very far distant from its present position. How far the glacier extended seaward has not been, and I think probably never will be, definitely ascertained; but a belt of very rough sea-bottom, known to fishermen as the 'Rough Ground,' strewn with large boulders, among which are many of Shap Granite, lies a few miles off the mouth of the Tees, and this was interpreted by Carvill Lewis as the moraine.

It is not to be supposed, however, that the boulders of Shap Granite were in all cases borne to their ultimate resting-place by the ice of the Teesdale Glacier—they are scattered right down the coast of Yorkshire, and even into Lincolnshire; and it seems to me most probable that those at least which are found to the southward of Robin Hood's Bay were carried by a later ice-movement. The advance of the Teesdale Glacier I believe to have effected the grooving of the rocks at Hob Hill described by Mr. Barrow (see p. 494), and the general west-to-east transport of local material associated with the Lower Boulder-Clay.

At some stage of the Glacial Period, the advance of the Scandinavian ice-sheet barred the access of the Teesdale Glacier to the coast-line—whether at an early or a late stage will be discussed subsequently; and the Teesdale Glacier was compelled to turn from its direct seaward path. Two courses lay before it—to turn northward into the Wear Valley, or southward into the Vale of York. The northerly route was preoccupied, however, by the native Wear-dale Glacier, which was perhaps already much encumbered by the pressure of the Tyne Glacier on the north, and consequently the route down the Vale of York was adopted. The watershed, which in pre-Glacial times separated the Tees drainage from the Ouse, was a very low one,¹ lying about on a line joining Bedale with Northalerton, where the Drift is now very thin, and over this the glacier passed. It received a great tributary from the Ure Valley, and possibly one from the Valley of the Swale, but I am rather disposed to agree with Carvill Lewis in thinking that Lower Swaledale was not occupied by a glacier. The western edge of the Teesdale Glacier, where it swept over into the Vale of York, surmounted hills 600 feet above sea-level, and may be presumed to have been of greater altitude. It stretched down to Esrick, where it left a splendid terminal moraine, and a second terminal moraine spans the Vale at the city of York itself.

¹ There was no doubt a very great sub-glacial denudation of the soft Triassic sandstone, but no attempt can be made to evaluate it. I think, however, that no material change was made by it in the position of this watershed.

The characteristic erratics of the western series occur throughout the Vale of York, and in particular the Shap Granite is found from side to side of the Vale, and even, on the western edge, to within 2 or 3 miles of the outermost lateral moraine, as at Lindrick Farm near Ripon.

The northern group of erratics was brought by an ice-movement, which may for present purposes be regarded as having originated in the Tweed Valley. The ice generated in the head of that valley appears to have flowed without hindrance as far as the neighbourhood of Coldstream, where, at one stage, instead of pursuing its direct course down to the sea at Berwick, it turned sharply round the projecting end of the Cheviots through an angle of about 140° , and took a course almost directly southward.¹

What the constraining agent was, which bent a great glacier 20 miles wide through so rapid a turn, is not quite so clear as in the case of the Teesdale Glacier. When we observe, however, the way in which the whole of the Eastern Scottish glaciers suffer deflection, either northward or southward, as they approach the coast-line, it seems impossible to resist the conclusion pressed upon us with such skill and force by the late Dr. Croll and Prof. James Geikie, that it was the overmastering influence of a Scandinavian ice-sheet filling the North Sea, and bearing down upon the whole coast-line of Britain, from Norfolk to Caithness. The Tweeddale ice was undoubtedly driven to the southward over the seaward portion of Northumberland, and, to judge by the great profusion of the porphyrites among the Yorkshire erratics, and the large proportion which they bear to the other erratics in certain deposits and in particular districts, I think it highly probable that the ice which swept the belt of porphyrite-lavas fringing the Cheviots, did actually invade the Cleveland Hills and much of the coast-line farther south. The Cheviot porphyrites form a notable element in the Drift as far westward at least as Scarth Nick, near Ingleby Arnecliffe, and I am disposed to regard them as the natural associates of the fragmentary marine shells, with the distribution of which theirs very closely agrees.²

It appears to me not improbable that the Tweed-Cheviot ice passed off the land on to the bed of the North Sea somewhere between the mouth of the Coquet and that of the Tyne, and that it re-invaded the land, under pressure from the east, somewhere about Roker, or perhaps a little to the northward of that place. The striations at Roker clearly indicate a movement in from seaward, and at several places on that coast worn flints have been found in the Drift.³ I have found them abundantly myself at West Hartlepool, and I think that they must have come from the sea-floor.

¹ P. F. Kendall & H. B. Muff, *Geol. Mag.* 1901, p. 513.

² For many important facts regarding the distribution of these rocks, see J. W. Stather, *Geol. Mag.* 1901, p. 17.

³ R. Howse, *Trans. N. of Engl. Inst. Min. Eng.* vol. xiii (1863-64) p. 173.

The last of the great ice-flows to be considered is the Scandinavian ice-sheet. The evidences of the approach of this great ice-sheet to the coast of Yorkshire are both direct and indirect. Scandinavian rocks of unmistakable character are found in Glacial deposits both on the coast-line and far inland. Mr. J. W. Stather found in my presence a beautiful specimen of rhomb-porphry, in a deposit of Boulder-Clay at an altitude of 810 feet above sea-level, on the hills above Lockwood: this is both the greatest altitude and the most westerly situation in which these rocks have been found in the district. The augite-syenite of Laurvig I have found on the shore between Saltburn and Redcar: this is the northernmost known occurrence of a Scandinavian rock in Britain.

Evidence is furnished by the consistent direction of the Glacial striae along the Yorkshire coast of the operation of an ice-sheet invading the country from the north-east, and the distribution of the Drift strongly reinforces this evidence.

I must reserve for later discussion the question of the order in which these three ice-movements took place, but it will render my description of the special phenomena of the ice-margin more intelligible if I say at once that the general order appears to have been:—(1) the Teesdale Glacier's unobstructed access to the coast; (2) the arrival of the Scandinavian ice-sheet and diversion of the Teesdale Glacier into the Vale of York; and (3) the invasion of the Scottish ice.

VIII. THE EXTRA-MORAINIC LAKES.

I have found it convenient to deal with the mass of complicated and mutually related detail by the adoption of an arrangement of the facts partly geographical and partly chronological. I shall describe first Lake Pickering—the lowest lake of the sequence, and the one which for a long period received practically the whole drainage of the northern, central, southern, and eastern parts of the area under consideration, leaving, perhaps, the western margin to drain independently. I shall then deal with its great affluent Newton Dale, and so pass up into the Eskdale drainage. Here it will be necessary to recognize and describe two distinct periods or phases. These two phases will be dealt with separately, and between them it will be convenient to treat of the lakes of the outer face of the Northern Cleveland Hills. The next area to be considered will be Iburndale and the Sneaton-Stainsacre recess, two indentations of the southern side of Eskdale, east of Goathland; then the coastal strip from Whitby to Filey, in order from north to south in four sections—Robin Hood's Bay, Peak to Cloughton, Burniston to Scalby, Scalby to Filey. This arrangement will follow closely the actual course of the investigation, and, while the first portion, from the Vale of Pickering to the outer face of the Cleveland Hills, will ascend from lake to lake through a continuous system of drainage, the second portion, from Iburndale to Filey, will descend

through another chain of lakes in the direction of a continuous drainage, finally reaching Lake Pickering again.

(1) The Vale of Pickering.

The geological and physical structure of this valley is simple. It is a long faulted synclinal trough of Kimeridge Clay, lying between the dip-slope of the Corallian Series on the north, and the Chalk-escarpment on the south. On the west, it is to a large extent shut in by a much-faulted tract of Jurassic rocks, from the Corallian down to the Lias; while on the east, along the strike of the Kimeridge Clay, it opens out into Filey Bay. This structure of the solid rocks would naturally give rise to an eastward-flowing river carrying the whole drainage of the basin; but this simple hydrographical arrangement no longer obtains. Drift-deposits of great thickness occupy the seaward end of the valley, and constitute the materials of the cliffs for a considerable distance to the south of Filey. They rise to a ridge which extends quite across the valley, and attains a minimum altitude of 130 feet.

At the western end of the valley there are two gaps in the Jurassic barrier—one broad and flat, *via* Coxwold and Gilling, having a summit-altitude of almost exactly 225 feet, at the village of Coxwold. This valley coincides with a couple of faults which bring down the soft Kimeridge Clay between harder rocks. The other gap is the narrow deep gorge of the River Derwent. This latter valley cuts through a watershed from 200 to 225 feet in height, and it bears all the characters of a lake-overflow of the first type—a direct overflow (see p. 481). The existing water-level in the gorge is well below 50 feet O.D. The floor of the Vale of Pickering is occupied by alluvium, consisting in part of fine laminated clay (Warp), and in part of sand with a little gravel. The Glacial deposits extend up the valley only a short distance from the seaward end, but a few small patches of gravel and small hill-cappings, mapped as Boulder-Clay, are near the western end.

The whole drainage of the country south of the Esk, except a strip a mile or two broad north of Scarborough, enters the Vale of Pickering, and instead of taking the simple and direct course to the sea at Filey, is all diverted, against the slope of the rocks and the grain of the country, and passes out into the Vale of York by the gorge at Kirkham Abbey.

The first suggestion that this anomaly was due to Glacial agency must, I believe, be accredited to Carvill Lewis, who made Lake Pickering one of the examples of extra-morainic lakes in his paper read at the Manchester meeting of the British Association in 1887. Mr. Fox-Strangways appears to have arrived independently at the same conclusion, and has supported it by new and valuable evidence in his paper on the 'Valleys of North-east Yorkshire,'¹ and in his

¹ Trans. Leicest. Lit. & Phil. Soc. vol. iii (1894) p. 333.

great Memoir on the Jurassic Rocks of Yorkshire. Mr. Fox-Strangways suggests that there was an original depression on the site of the present overflow, occupied by a small stream flowing towards Malton (Mem. Geol. Surv. 'Jurassic Rocks of Britain' vol. i, 1892, pp. 423-24):—

'Now, if we suppose the eastern end of the Vale of Pickering to be blocked by Boulder-Clay, the drainage must naturally find its way out at the lowest point; this appears to have been at the head of the little valley which we suppose to have occupied the position of the present course of the Derwent below Malton. By gradually lowering the higher part of this valley, it would in course of time change its slope to the opposite direction, and eventually drain the Vale of Pickering, which during this period must have been a lake.

'The edge of the escarpment, where it is cut by the present valley at Kirkham, is between 200 and 250 feet above sea-level; the level of the Boulder-Clay which now blocks the Vale of Pickering near Filey is 130 feet; so that it only requires the Glacial deposits along the seacoast to have been about 100 feet thicker, to have sent the water over the depression to the south of Malton.'

Mr. Fox-Strangways recognized that such a lake should have left traces of its strand-lines, and made the following observations on that point:—

'The most marked terrace at the present time is that on the north side of the valley at Hutton Bushel, the level of which is a little more than 200 feet above the sea, that is, exactly at the level that a beach would be formed when the exit from this lake was across the hills south of Malton. Below this there are two minor terraces, not so well marked, at about the 100- and 140-foot contour, which probably denote periods during which the denudation of the Malton gorge was for a time checked. Besides this there are no distinctly marked terraces, but there is a considerable amount of gravel here and there, all of which is below the 250-foot contour.'

While in thorough agreement with Mr. Fox-Strangways as to the main lines of his explanation, and very grateful for the valuable data which he has furnished, I am compelled to differ from him regarding three points—small points indeed, but, in view of my work in other areas, important.

The first relates to the nature of the barrier which held up the waters of Lake Pickering. Mr. Fox-Strangways considers that it was a barrier of Boulder-Clay, which has since been lowered by denudation to the extent of 100 feet. Such an amount of post-Glacial denudation, except in the erosion of a valley or gorge, is quite unparalleled. Everywhere we find moraines, drumlins, eskers, and kettle-holes preserving their sharpness of form in great perfection; and I find it much easier to believe that the ice which laid deposits upon the tops of the hills, at altitudes of 450 to 600 feet, both north and south of the Filey barrier, was the obstruction. I think that Mr. Fox-Strangways will himself accept this explanation, which indeed he offers for a similar case at Scalby, only a few miles to the northward.

Another point of difference is very similar. I have mentioned that there are two breaches in the hills which shut the Vale of Pickering to the westward—the one by which the Derwent makes its escape, and the Coxwold-Gilling depression. The difference between their respective summit-levels, is very small, but in the

event of a lake overflowing this way the advantage of even 5 feet would be decisive; it is, however, by no means certain that the Kirkham-Abbey route had the initial advantage. Mr. Fox-Strangways is of opinion that it had, and that the Coxwold-Valley erosion has no connection with the river-systems of the country, and is probably of later date than any of these river-gorges. I am unable to accept his explanation, which is, moreover, rendered unnecessary, in my judgment, by this consideration, that the Coxwold Valley itself was blocked by ice. The great glacier which descended the Vale of York obstructed the drainage of the western edge of the Cleveland area, and produced upon a small scale phenomena similar to those which are displayed in the east and north. It extended for more than 10 miles, perhaps much more, down the Vale of York below Coxwold, and its terminal moraine at High Catton attains an altitude of more than 100 feet. It therefore seems reasonable to suppose that at Coxwold the ice rose quite as high as the watershed. More than this, the officers of the Geological Survey have mapped Boulder-Clay at an altitude of 279 feet in the Coxwold-Gilling Valley, which was, I believe, invaded by a lobe of the glacier.

The third point of difference is as to the exact nature of the gravel-bench at Hutton Bushel. Mr. Fox-Strangways regards it as a lake-beach, but reasons fully stated later have led me to conclude that it partakes more of a deltaic nature, and that it came into contact with the static waters of Lake Pickering only at the western extremity.

Mr. Fox-Strangways has referred in his Memoir to a singular abandoned valley entering the Vale of Pickering in the south-west, near Settrington. He remarks that the cause of the alteration of the drainage is not very clear. I would, however, point out that this valley is excavated in the eminently porous and absorbent Corallian rocks, in which deserted valleys abound, as they do in the Chalk-area of the Wolds. Two general causes of these deserted valleys may be here noted:—(1) the dry valleys of the Chalk Wolds, and certainly many of those in the Corallian limestones, were excavated during the Glacial Period, when the rocks were in a frozen state, and therefore were impervious to water; and (2) many valleys in the Corallian limestones have been abandoned by streams which have found their way into subterranean courses, in the manner so common in areas of compact limestone. I have visited the spot, and have no suggestion to offer; but, so long as the phenomenon is unexplained, it remains a possible exception to generalizations respecting the intimacy of the association of deserted valleys with evidence of ice-action.

The evidence adduced by Mr. Fox-Strangways may, I think, be regarded as placing Lake Pickering among the well-established facts of Glacial geology; and we may proceed to consider one of the affluent streams, and see what conclusions may be drawn from its features. There are many large valleys opening into the Vale of

Pickering, some of which cut through the cover of the Oolites and produce singular inliers of Lias. These all lie in the western half of the area, and are probably due to the flatness of the top of the Cleveland anticline. Streams rising near the axis find difficulty in penetrating the harder beds of the Oolite, and so take an uncertain course over the high flat moorland. Hence some stream-heads, as Mr. Fox-Strangways has pointed out, have been captured by the Esk with its shorter course to the sea, and consequent steeper fall. When these moorland-streams pass away from the anticlinal axis, the dip of the rock increases, the fall steepens, and the increased cutting-power so obtained enables them to carve through the hard Lower Estuarine Sandstone and make a slash in the underlying Lias.

In the eastern region, the beds have not been thrust up so high, and the streams do not penetrate to the Lias. With the exception of the anomalous valleys near the coast, to which reference will be made in a later section of this paper (p. 535), these valleys are mainly cut in the Middle and Upper Oolites, and are of comparatively small dimensions. One, however, Newton Dale, has long been an object of interest to me and of wonderment: because of its immense depth, and the way in which it passes completely through the watershed. Reflecting upon these characters, with the light obtained by studies of Glacial overflows near Ripon and Knaresborough, I was brought to the conclusion that Newton Dale must be the overflow of a glacier-dammed lake in the Eskdale country. An inspection of a map showed that if the normal outlet of the Esk were closed, this would, by its altitude, be the outlet. This clue led to the unravelling of the whole chain.

(2) Newton Dale.

I have used this valley to illustrate so many features of overflow-valleys, that comparatively little remains to be said. From Pickering, where it debouches into the Vale of that name, it quickly assumes a gorge-like character, the very steep sides rising to 300 feet or more, according to the magnitude of the successive Oolitic escarpments which are cut through. Above Raindale, where the largest tributary valley enters, the Dale exhibits a series of bold windings, as already mentioned, which display the characters of the ordinary meanders of a stream, having steep outer curves and comparatively gentle inner curves.

The amount of drainage passing down Newton Dale is very small, especially above Raindale, and for $2\frac{1}{2}$ miles at the upper end there is no continuous stream, but a bog, with an occasional strip of running water. For half a mile at the actual summit there is a great peat-bog, and no stream whatever except artificial drains. This final half-mile is the most significant part of the valley, and must therefore receive a rather detailed description. The watershed is here cut completely through by Newton Dale as a broad, flat-floored trench, more than 50 feet deep, with steep sides. The peat is evidently of great depth. I spent some hours here, in

January 1900, boring the peat with a set of rods. I found that at the apparent sill or intake at Fen-Bog Houses, there was a depth of $16\frac{1}{2}$ feet of peat below the level of the water in a drain, the water-level being about 4 to 6 feet below the bog-level. Another boring touched rock below 13 feet of peat; and a third reached gritty clay at between 13 and 14 feet. The actual altitude of the rock-floor in these cases was almost exactly 525 feet above sea-level. If the peat were removed, the channel through the watershed would appear as a clean cut, 75 feet deep. I was informed by a signalman on the railway that the peat was much deeper to the southward, and that piles were driven into it to a depth of 60 feet in the construction of the railway. This part of the valley, known as Fen Bogs, is a true lake-overflow, as pronounced as any of the 300 or more which I have seen.

On the northern side of the watershed the valley inosculates with that of Eller Beck, the normal valley of a stream which takes a rather aberrant course. It flows in from the eastward, receiving tributaries of about equal volume from the north and south; when it reaches the head of Newton Dale, a little over the actual sill of the intake, it turns northward and flows through a V-shaped valley to join the Murk Esk (see fig. 4, p. 504 and Pls. XX & XXI). Mr. Fox-Strangways, in the works quoted, suggests that Eller Beck originally flowed through Fen Bogs, and that it was captured by the headwaters of an active tributary of the Murk Esk, in the fashion since made familiar to English readers by Prof. W. M. Davis. Mr. Fox-Strangways regarded the great trough at Fen Bogs as a reach of the Eller-Beck valley, which had lapsed into disuse by the diversion of the stream.¹

A comparison of the sections of the two valleys will show that this explanation is inapplicable, the Fen-Bogs channel being far too large to have been cut by such a stream as Eller Beck, and it belongs to a type wholly different from that which such a stream would produce. The water-level in Eller Beck, at its nearest approach to Fen Bogs, under conditions of heavy rainfall is only about 6 feet at most below the sill of the Fen Bogs-intake, but it flows over a bed of large boulders. It must have very narrowly escaped capture by Newton Dale.

At the outset of this enquiry, I recognized that, if Newton Dale were the overflow of a glacier-lake and subject to torrential rushes of water, then a vast quantity of detritus must have been carried into the Vale of Pickering to form a great gravelly and bouldery delta. Reference to the maps of Pickering showed that such a fan of gravel, the only one on the north side of the Vale, does exist

¹ Since this was written (in August 1900), Mr. F. R. Cowper Reed has published a full discussion of the evolution of the rivers of East Yorkshire. With most of his conclusions I am disposed to agree, indeed, geologists in Yorkshire have for some years employed like explanations; but, as to the history of the Fen-Bogs channel and a few other similar cases, I am compelled to dissent, as the sequel will show.

there; and an application to my friend Dr. Thornton Comber, of Pickering, elicited the following valuable notes:—

‘The gravel-deposit is only marked as of a small area at Pickering. As far as I know, the breadth is accurately recorded, but the deposit really extends all the way to Rishborough, and is found about 6 feet below the present surface whenever any digging has been performed. The stones are chiefly large, 1 to 2 feet in diameter, and rounded. They chiefly consist of hard moorland-grits. Occasionally I have found pieces of whinstone—a large boulder of this, weighing about a quarter of a ton, was found embedded some 6 or 7 feet deep in the clay, when the men were baring the surface of the limestone, in one of the quarries at New Bridge, at the mouth of Newton Dale.’

Here, then, appears to be a delta composed mainly of the harder rocks out of which Newton Dale was excavated, with some foreign rocks, notably a whinstone, which Dr. Comber identifies with the

Fig. 4.—Comparative series of sections across the valley of Eller Beck and Newton Dale.

Cleveland Dyke that crosses the hills about 2 miles north of the intake at Fen Bogs. The coarseness of the material agrees well with the expectation founded on the steep fall of the valley.

The area of gravel mapped as surrounding the Pickering outfall is about 2 square miles, but Dr. Comber's data indicate that there

is a much greater mass of gravel buried beneath a layer of Warp. The appended map (fig. 5) shows the surface of the ground at Pickering, which is seen to have the form of a digitated fan, precisely similar to an Alpine *cône de déjection*, but with a lower slope. It will be shown in the sequel (p. 531) that Newton Dale ceased to act as an overflow long before the close of the Glacial Period, and the layer of Warp which partly covers the delta is seen to have considerable significance.

Fig. 5.

[The gravel-covered area is copied from the 1-inch map of the Geological Survey.]

(3) The Eskdale System of Lakes.

The existence of an overflow at Newton Dale clearly implies a lake on the northern side of the watershed, and this could be produced only by an ice-dam blocking some part of Eskdale at an altitude exceeding 525 feet, the level of the overflow.

Direct confirmation of this implication was obtained from a first inspection of the maps. A series of 'severed spurs' forming an aligned sequence of overflows was found to extend from Eskdale across the spurs separating the Valley of the Esk from that of the

Murk Esk and Eller Beck. These channels all indicated a flow towards Fen Bogs. Details, with the field-observations, will be given later. The distribution of the Drift furnished equally clear evidence of the ice-invasion which would produce such a series of barriers.

Boulder-Clay and other Glacial accumulations extend completely across the Northern Cleveland watershed from Whitby westward to Stonegate; and they not only extend far up the Valley of the Esk itself to Lealholm, but also follow closely the boundary that might be assigned, solely on the evidence of the overflow-channels, to the ice in the valley of the Murk Esk. Indeed the precision with which, upon this evidence alone, I have been able to delimit the ice-margin convinces me that, in lake-overflows, we have a means of defining Glacial boundaries of the greatest value.

At the maximum extension of the ice, the Northern Cleveland watershed, as I have stated, was completely overridden as far west as the Stonegate Valley; but the lobate ice-margin appears never to have crossed Lealholm Rigg, or at least to have left no clear trace either as overflow, moraine, or any very definite Drift-deposit, though, in the village of Lealholm at 625 feet, clay with foreign stones is exposed, and scattered pebbles occur above the 700-foot contour.

An ice-lobe must have ascended Eskdale for a mile above the village of Lealholm, and laid down a moraine extending quite across the valley, obliterating the old course of the Esk.

This moraine has been cut through by the railway at its lowest point, and consists apparently of stony Boulder-Clay with fragmentary shells, but without admixture of sand or gravel. On the southern side of Eskdale, much Drift is observable up to altitudes of about 700 feet; but no recognizable moraine which could be referred to this stage is to be seen until Glaisdale is reached, where a great ridge of Drift extends across the valley with a minimum altitude of 450 feet, and a height above the valley which it obstructs of over 100 feet. In similar relation to the main valley is another morainic barrier across the Butler-Beck (Egton-Grange) valley.

The continuation of the line of maximum extension is much more definitely indicated from this moraine (which may not represent the extreme limit of the ice, and on the other hand may represent a later phase when the ice-front extended in a more westerly direction though not at so great an altitude) onward by a splendid series of overflow-channels. The first of these is a great trench deepening and falling towards the south, which cuts across the edge of Murk-Mire Moor. The sill of the intake is at an altitude of 714 or 715 feet (Ordnance Survey B.M.), and it extends for a distance of $1\frac{1}{2}$ miles as a deep groove of characteristic section, filled with moss and swamp so as to be impassable in the winter, when alone I have seen it.

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 iceward retaining-wall, but in some parts that function is performed by some gravel-mounds. This shelf runs out, and disappears near the

Hollins just below the 675-foot contour; and as it fails to indent the 650-foot contour, it is clear to me that it reached the quiet waters of a lakelet at 670 feet or thereabouts.

Where this overflow terminates, a mass of gravel obstructs the valley of West Beck, which cuts over into the solid rock to avoid it, and so forms Nelly-Hay Force. This is probably both delta and moraine.

Between the West-Beck valley and the valley of Eller Beck, on this parallel, there stands forward a bold spur, Two-Howes Rigg, against which the ice must have abutted, ponding up the drainage of West Beck; for there is a beautiful marginal overflow, Moss Slack, cutting round the shoulder of the hill and just getting through the 675-foot contour. The precise correspondence of level between the Murk-Mire outfall and the Moss-Slack intake cannot be fortuitous.

The Moss-Slack overflow at its outfall-end cuts contours as low as the 625-foot contour, but below that an existing stream may be responsible. The way thence is open to Fen Bogs. (See Pl. XXII.)

The evidence of these overflows proves that at the maximum extension of the ice a lake was held up in Eskdale to an altitude of over 725 feet, lowering to 714 feet; and assuming that it extended no farther than the gap at West-Bank House (near Kildale), it would have been about 11 miles long and not less than 400 feet deep: it would have had ramifications up all the tributary valleys. I propose for it the name of Lake Eskdale.

Lake Eskdale drained by the Murk-Mire-Moor overflow into Lake Wheeldale, which stood at an altitude of 675 feet and was about 3 miles long. Its extreme depth was about 225 feet.

Lake Wheeldale drained over Moss Slack at 675 feet into a small lakelet in the Eller-Beck valley, the extreme altitude of which, determined by the top of the Fen-Bogs notch,¹ was about 650 feet. This lakelet, which I have always called the 'Vestibule,' but which it may be more convenient to particularize by a geographical name, Eller-Beck Lake, was probably 150 feet deep.

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 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. I do not think that this affected the Moss-Slack

¹ In determining the site of an original watershed, it should always be borne in mind that an overflow cuts back as well as cuts down. I think that the original water-parting between Newton Dale and Eller Beck was at least as far back as Scar Nick, and Thack Sike was a tributary of Eller Beck.

Fig. 6.—*Intake of the Castle-Hill oxbow viewed from Moss Swaney.*
(*The sill is 50 feet above the floor of the main valley.*)

Fig. 7.—*Randay-Mere valley viewed from the south.*

[The above figures are reproduced from photographs by Mr. Godfrey Bingley.]

overflow. The next shrinkage was a much more considerable one—the ice-margin withdrew 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. Traces of the scarp into the hillside are well seen above Struntry Carr, indenting the 650-foot contour.

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.¹

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, and led to the abandonment of the oxbow there. 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.² The view of this deserted channel from the main Moss-Swang valley is very striking. (See figs. 6 & 7, p. 508.)

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.

There is a shallow groove running behind the church at Goathland, which may have been cut at the final stage of this lake. It is a few feet, probably not more than 5 or 6, below the level of the Fen-Bogs overflow; but there is another interest altogether attaching to it, in the form of a scarp in hard grit, the same which forms the sill at Fen Bogs, fronted and covered by bedded gravel

¹ The last-named valley contains the reservoir that supplies Whitby with water. In the course of some repairs executed upon the floor of the reservoir, a great thickness of superficial deposits was encountered. Mr. G. B. Williams makes the following remarks upon them:—‘At the bottom of the reservoir there is a deposit of clay and silty sand, mixed with detritus from the surrounding rocks, and interstratified with layers of peat, the whole being 60 feet to 70 feet deep’ (Proc. Inst. C. E. vol. cxxxvii, 1899, p. 357). The author gives no diagram of the section, and I suspect that some disintegrated rock *in situ* is included in his description.

² It is quite possible that the oxbow was produced by a slight re-advance of the ice blocking the lower end of Moss Swang. There are signs elsewhere of such an oscillation.

Fig. 8.—Serial sections across the overflow-channels on
Mirk-Mire Moor.

Fig. 9.—Map of the Eskdale system of lakes, at the levels corresponding with the Lady-Bridge-Slack and Moss-Swang overflows.

with a few foreign stones. The level at which this is seen is about 560 feet. This is about the level of the top of the Moor Grit at Fen Bogs.

At several points along the approach to Fen Bogs, a similar scarping is observable. For example, at Thorn-Hill House it can be seen extending across four fields; and farther on, at Moss Dyke, where the feature is very marked, there are clean sections visible, which show that although the scarp coincides in altitude with the outcrop of a hard rock, it is really due to an excavation in a facing of Drift-material, perhaps the delta of Moss Slack. At Thorn-Hill House the surface is Boulder-Clay with erratics, and at Moss Dyke the section is as shown in figs. 10 & 11.

Fig. 10.—Section through the feature at Moss Dyke.

Fig. 11.—Section 10 yards upstream from fig. 10, showing gravelly rainwash bedded against grit.

A well-marked scarp is also visible about Hollin House, near the Randay-Mere outfall, for a distance of fully half a mile. It is at the same altitude as that mentioned above, namely, 550 to 560 feet.

Two features must be mentioned in conclusion, the deltas. At the outlet of the Murk-Mire-Moor channel, from Hollin House to Hazel Head, there is a considerable accumulation of gravel which may represent the delta of that overflow, but the erosion of the gorge would not supply a very large amount of material.

The lower Moss-Swang and Randay-Mere overflow, however, is on a gigantic scale, much of it being at present 100 feet deep by

200 yards wide : we accordingly find at each outlet a vast accumulation of gravelly debris. That at the end of the Randay-Mere segment has, with the Boulder-Clay and other material thrown down directly by the ice, completely filled the old valley of West Beck, probably to a depth of 250 feet, and has compelled the stream to cut a new channel for itself at Scar Wood, in the form of a great rocky ravine nearly 200 feet deep.

About Julian Park, near the Randay-Mere outfall, great quantities of boulders are found in the fields. The separate outlet of the Moss-Swang valley at the lateral escape is also strewn with large boulders.

Fig. 12.—Section from Julian Park to Two-Hoves Riggy.

We may now consider the conditions prevailing in Lake Eskdale during the formation of the Moss-Swang outflow. The intake itself presents some features of interest. Like the Fen-Bogs intake, the last stages of cutting were through, or into, a hard bed of grit, which forms a conspicuous platform in front of the actual sill. Along the hillside to the west ward there is a very steep and strong scarp, probably due to the ice thrusting forward and confining the inflowing waters against the hillside.

Of beaches in Lake Eskdale I am unable to cite a clear example. At many places the hillsides are notched, but there is only one level at which the signs are at all widely prevalent: this is at about 560 or 575 feet. I have observed scarping at approximately this elevation at the following localities:—

Bramble Carr, near Danby Parsonage : about 560 feet.

Scale Foot, near Castleton : 560 feet.

Hornby House and Winsley Hill, Danby : above 575 feet.

Foul Green, Commondale, just above the old mine-shaft, two scarps at 575 and 600 feet.

At the same levels are two very pronounced terraces in the gravel-mass in Bellman Lane, Danby-Dale End, and along the hillside above Lealholm, especially near Hole-i'-th'-Ellers for a considerable distance, at about 575 feet.

There are also remarkable benches of gravel at Stonegate at 560 and 575 feet respectively, to which more particular reference will be made later.

These scarps, although in some instances clearly connected with outcrops of hard rock, are in others, as for example at Scale House and at Danby-Dale End, cut in gravel ; and I think that they may be

regarded as marking the level of Lake Eskdale at the stages of cutting represented by the grit-outcrops at the Moss-Swang intake.

The remaining phenomena of Lake Eskdale can be understood only by reference to the conditions which prevailed in the country outside the watershed of Northern Cleveland.

(4) The Lakelets of Northern Cleveland.

The evidence already adduced has made it clear that a great press of ice bore upon the northern face of the Cleveland Hills. At the western end denudation has almost completely swept away one side of the Cleveland anticline, and left in its place a deep rectangular recess overlooked by a serrate escarpment, which exposes the sections of a number of beheaded valleys. Whether marine denudation has had any part in this, or whether it has been brought about solely by the action of rivers which have encroached by their headwaters and by the capture of tributaries, I am unable to say; but the cases of Lonsdale, the Leven, and Sleddale, to be presently mentioned, seem to indicate that subaërial denudation may have been the sole agent.

The distribution of erratics and other signs show that, at the maximum extension of the ice, an overflow of water may have taken place by every notch in the escarpment, though only of three places can this be positively asserted.

The Whorlton Recess.

At the western extremity of the escarpment there occurs the only example of a valley opening to the northward. This valley, Scugdale, is hemmed in by lofty ridges rising to upwards of 1000 feet except at one point, where a gap occurs in Stony Ridge on the west side of the valley. Here a narrow, sharply-cut notch breaks through the 1000-foot contour, and forms the intake of a deep channel, Holy-Well Gill, which has all the characteristics of a lake-overflow.

I have examined this valley on two occasions, and though I felt that there seemed to be an inherent improbability in the occurrence of an overflow at such an altitude—the highest that I have observed in the Cleveland area—at this particular place, yet the character of the valley compels me to include it. The Drift in Scugdale does not extend, or is not traceable, to so high an elevation. At Sparrow Hall there is gravel with erratics up to over 600 feet above sea-level, but along the hillside near the overflow, though traces of gravel are visible up to 925, I found no erratics above 875 feet. When this overflow was in operation, the valley must have been quite blocked with ice.

Simultaneously with the operation of this overflow, a small lakelet was formed in a minor recess above Scarth Wood, which cut a well-marked channel through the watershed into the valley leading down to Osmotherly; but its operation seems to have been of brief duration, and a slight recession of the ice-front opened a lower notch, the

fault-valley of Scarth Nick, which now carried off the waters both of this lakelet and of Lake Scugdale.

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.

Carlton Bank.

This, the next opening to the east of Scugdale, is a valley of the southern slope which has been beheaded.

The intake-notch is very broad, and there is a broad flat sill at an altitude of about 930 feet. The watershed is almost on the extreme edge of the escarpment. I have found erratics right across the sill and on the hills a little above it, so that the ice here must have attained as great an altitude as in Scugdale; but though there was probably some wash of water over into the Rye drainage, there cannot have been much, as the escarpment is very straight along here, and there is no recess which could have held a lake.

The breach at Donna Cross has a double head a little over the 1000-foot contour. It shows no definite signs of overflow, and the same may be said of Carlton Bank; but the next opening, the last in the series, is of a different type altogether.

The Ingleby-Greenhow Corner.

The re-entrant angle of the Cleveland escarpment at the eastern end is breached by a splendid overflow-channel, which had been identified as such (before I saw it) by my friend, the Rev. J. H. Hawell, M.A., F.G.S., who has accompanied me over much of the Cleveland area. It is a deep, square-cut notch, carrying no stream at present. Probably it drained a considerable part of the ice-margin for a long period. It has no complications, and is a simple example of the 'direct overflow.'

Kildale.

This remarkable valley is as interesting to the geographer, and especially to the student of river-action, as to the glacialist.¹

Its trough is a nearly direct prolongation of the axis of Eskdale, and whatever cause is responsible for the selection by the Esk of its valley must also have determined the formation of Kildale. The

¹ The following remarks were written in their present form in August 1900, before I had any knowledge of Mr. F. R. Cowper Reed's work in the district.

River Leven, which flows down Kildale, takes its rise in the moorland to the south, and makes two turns nearly at right angles, so that its upper course is actually parallel to Kildale, but in the opposite direction. Here is very clearly a case of river-capture; and this conclusion is greatly strengthened by the fact that a tributary, in Lonsdale, similarly flows eastward and turns abruptly into the westerly drainage of Kildale. I think that these cases of capture belong to a pre-Glacial time. Lonsdale certainly was incorporated with the western drainage before the Glacial Period, but the headwaters of the Leven are not so clear a case. It is possible that both the Leven and its neighbour Sleddale Beck were captured by the western drainage before the Glacial Period, and that Sleddale Beck returned to its original direction.

Kildale is obstructed at its western outlet by a moraine, which has compelled the Leven to make a new cut, the fine gorge at the Bleach Mill. The moraine is 100 feet above the floor of the valley, and the lowest part is at the northern end where the gorge is cut. The upper part of the valley is largely occupied by Drift-deposits, consisting mainly of sand and gravel, which cover the central part of the valley, and Boulder-Clay is mapped along the margins.

Lonsdale, a valley long attached to the western system of drainage, opens into it on the northern side. Its high watershed is notched slightly at the top, at Gribdalegate, by what I take to be a small Glacial-lake overflow. The head of Kildale contracts in a very marked fashion before reaching the point of entry of the Leven, which is a very small and insignificant stream; then it expands to the watershed at West Bank. The watershed is broad and flat, and is occupied by an extensive bed of peat. Sleddale Beck comes in as soon as the watershed is passed, and is a large and swift stream, many times the volume of the Leven. It flows at first through a deep bed of alluvium, and then enters a more gorge-like region with steep rocky sides composed of the hard grit, instead of the Lias which formed the upper part of its course. It was early impressed upon me that some extensive overflow must have taken place across this pass during the Glacial Period, and I have taken some pains to form an idea of the exact order of events. The altitude of the Bilsdale overflow, which at the maximum extension of the ice is the only one by which an escape could be found to the westward for water in Eskdale and Kildale, is so much above the highest level of the Eskdale Lake (725 feet), that an inflow must have taken place from Kildale during that stage; and I can discover no evidence of reversal of this flow, though it might have occurred as a temporary episode, and left no sign. There is, however, such an uninterrupted series of overflows into the Goathland area from the highest (725 feet) down to the lowest phase of Moss Swang (560), which is below the level of the West-House watershed, that I do not think a reversal of flow at all probable. This being so, there must have been a flow of water through the West-Bank pass into Eskdale. At the higher levels of Lake Eskdale (725 to 715 feet) there would have

been a depth of about 150 feet of water over the pass; but as the Moss-Swang overflow was deepened, the Kildale pass became awash, and at the lowest level the overflowing stream would actively cut its way across. The evidence of this stage is very clear. Any overflow through the pass in either direction would, of course, be checked by the tranquil waters of a lake, and such coarse detritus as it carried would be cast down in the form of a delta. Now, at Commondale, where the narrow valley of Sleddale Beck expands, there is a great mass of gravel extending up the southern slopes to about the 600-foot contour, and forming a very well-defined plateau at 550 to 575 feet O.D. It has a very steep face looking eastward, due perhaps to the winding of the beck against it. The gravel consists mainly of Jurassic sandstone, but there are also many foreign stones, the most significant of which is a small boulder of Shap Granite. I infer that this material constitutes the delta of an overflow down Sleddale Beck, which was arrested by standing water at levels from 600 feet down to about 560 feet.

The gravel extends down Eskdale for about 2 miles, as an infilling of the floor in which the river has cut a new valley. At Holme Bank it forms a barrier across the valley, and the river has cut through the live rock on the north side. Here the top of the gravel-mass is flattened off at an altitude of between 525 and 550 feet, which I think represents a stage of Lake Eskdale when the withdrawal of the ice-barrier at Moss Swang opened a free way to the Fen-Bog overflow, the level of which is about 525 feet, a sufficiently close correspondence to be worthy of observation.

This second plateau is very distinctly lower than the one at Commondale, and I regard it as evidence of a partial redistribution of the materials of the upper delta when the lowering of the lake caused an extension of the stream across its delta. A third stage is represented by a gravel-flat extending to the eastward of the Howe at Danby, at an altitude just above 500 feet. This, however, belongs to a phase of the later history of Lake Eskdale which cannot be described at this stage.

I may now say a few words about the post-Glacial history of the West-Bank drainage.

Whether Sleddale Beck was ever captured by the Leven drainage or not I am unable with any confidence to affirm; but if, as I have surmised, it had been, then the great flow of water which took place eastward to Lake Eskdale must have had the effect of cutting back the watershed and recapturing it. This shifting of the watershed would gradually begin to operate upon the channel between Sleddale and the Leven across West Bank. If the erosion were arrested at this stage, we should find that the Leven would remain a constituent of the western drainage; but if, on the other hand, the erosion proceeded farther, we might have the Leven in its turn recaptured. This view I held at one time, but subsequent investigations have somewhat weakened my confidence, and I am content to state the facts and the alternatives, and draw no deductions.

I have ascertained by levelling, that the watershed on the peat-bog at West Bank is 584 feet 6 inches above O.D. I made an almost complete traverse of the valley here, by a series of seven boreholes, extending from the edge of the valley on the south to the railway which is close to the north side of the valley. The first boring gave:—

	Feet.		Feet.
Peat	11½	4th. 20 yards N. Surface	585½
Clay, soft clay or peat. Hard blue sand in lower part.	6½	Peat... ..	17
	<u>18</u> or 566½	5th. 20 yards north.	16
	<u>—</u> feet O.D.	Peat	16
		Gritty clay.	<u>—</u>
			<u>16</u>
2nd. 15 yards to N. Surface	585½ feet.	6th. 20 yards north.	
Peat	15	Peat	13
Clay, gritty clay ...	7½	Impenetrable obstacle of wood.	<u>—</u>
	<u>22½</u> or 563		<u>13</u>
	<u>—</u> feet O.D.		
3rd. 13 yards to N. Surface	585½ feet.	7th. At the railway.	
Peat	16½	Peat	16
Gritty clay	0½	Buttery blue clay with particles of grit-stone	1
	<u>17</u>		<u>17</u>

These borings, which were made by me, with the kind assistance of Mr. Robert B. Turton (of Kildale), show that, even if, as seems probable, the boreholes, with the exception of Nos. 4 & 6, actually reached the Lias, the rock-floor of the valley here is below the level of the Leven, and it is very hard to understand why that stream does not flow eastward to the Esk.¹ Four possible explanations suggest themselves:—

1. That the Leven has been diverted by human agency.
2. That it has been obstructed by peat growing over a flat too broad to permit of free drainage.
3. That it threw down a delta where it reached the flat, and that it subsequently flowed round the margin of that delta.
4. That its old channel, now built up by peaty accumulation, is actually deeper than the rock-barrier at West House.

The first of these has little to commend it, though the Leven is now controlled by an artificial embankment. Between the other explanations, in the absence of the necessary data, I do not attempt to judge.

¹ [Other borings, made in January 1902, show that sandstone-rock comes to within 5 feet of the surface along the road between the watershed on Peat Carr and the River Leven; but borings beside the Leven were carried to a depth of 11 feet 8 inches in gritty clay.]

Fig. 13.—*View looking up Ewe-Crag Slack. (The white objects are boulders of grit.)*

Fig. 14.—*View looking down Ewe-Crag Slack. (The bluff on the right is the feature shown on the left of fig. 13.)*

[The above figures are reproduced from photographs by Mr. Godfrey Bingley.]

Kildale to Girrick Moor.

To return now to the consideration of the outer face of the Cleveland Hills. The country between Kildale and Roseberry Topping is of complicated form, and though I think it probable that lakelets with their overflows may have existed, I have seen in the course of a rather imperfect examination no clear traces. At Pinchinthorpe a small overflow is, I think, traceable out of the head of High Bonsdale, but I attach no importance to it.

Passing eastward, two comparatively low gaps are met with, in the great escarpment to the east of Hutton, formed by the two heads of Sleddale. The higher of these, Highcliff Gate, is below 950 feet O.D., but there is nothing in the arrangement of the contours to suggest an overflow, and I have not examined it. The other, known as Bold Venture, is a flat about a quarter of a mile wide, immediately below the 800-foot contour. Though its aspect on a contoured map is unpromising, I examined it, and was rewarded by some interesting observations.

On the eastern side of the gap (at 800 to 825 feet) are abundant erratics, among which I observed Cheviot porphyrites; and on the western slopes I also found many pebbles, including porphyrite and ash. The broad gap itself is encumbered with gravelly material of considerable thickness, cut into a close-set series of mounds with their long axes running down the valley. To the south of this Drift-barrier is a great tract of peat. Some overflow must have gone across here, both from the actual drainage of the ice, and also from a temporary lake in its advance and retreat, but no definite channel can be traced.

From Bold Venture in an easterly direction the watershed, save for Highcliff Gate, is high and unbroken for a distance of about 6 miles measured in a straight line. Then ensues a region of great interest, where the watershed is traversed by a succession of direct overflows, three in number, diminishing in altitude from west to east.

The first of these is Ewe-Crag Slack, a great winding valley which for the first half-mile has a very slight inclination; then it rapidly steepens after cutting through a thick bed of hard grit, and enters the valley of Black Beck¹ a normal moorland stream-course. The intake of Ewe-Crag Slack is turned sharply to the westward, and opens out in a great swampy area. The first half-mile of the slack is occupied by a deep accumulation of peat. In order to ascertain the exact form of this part of the valley, I made a series of fifteen transverse sets of borings or probings (54 in number) into the floor, and found that, agreeably to expectation, the greatest depth of peat was at the point where the peat-moss sloped up stream as well as down. Here a depth of 21½ feet was attained, and the boring ceased in tough deposits, not rock (see Pl. XXIII & figs. 13, 14, p. 518).

¹ So named on my maps. It should be Haw-Rigg Slack, as on the Ordnance-Survey maps.

Fig. 15.—Relief-map of the country between *Commondale* and *Doubling Castle*. (Scale: 2 inches = 1 mile.)

The overflow first came into operation at an elevation of a little over 800 feet, and it cut down to below 775 feet, probably about 750 across the watershed. There is no stream at present flowing in the upper half-mile, but where the slope steepens a small stream emerges from the peat-moss and trickles down through the dried peat of the steeper region, sometimes in an open channel. Often for considerable distances, however, it is arched over by peat, and down to the confluence with Black Beck it can be bestridden at any place. The usual features observable in the meanders of overflow-channels are seen in this gorge, and there are lofty crags along the west side for a considerable distance. Near the confluence with Black Beck, at 625 feet O.D., is a great mass of gravel which has yielded many erratics, including Cheviot porphyrites, and one example of the Norwegian rhomb-porphry.

This gravel-mass then spreads out and forms two distinct terraces (see p. 512), at 600 feet and 575 feet O.D. respectively. These represent the two halts in the lowering of Lake Eskdale.

So great an overflow as this, might be expected to bear some relationship to a correspondingly extensive lake-area on the northward, and this expectation is fully realized by an examination of the outer slopes of the hills. Not only is the intake connected with a large recess in the hills, but a suite of 'severed spurs' show that upon it converged the drainage of a considerable chain of lesser lakelets. The evidence of the distribution of Drift-deposits is consistent with that of the overflows. Mr. Barrow¹ remarks

'There can be no doubt that this high ground [above Guisborough, on Moors-holme High Moor, and on Danby Low Moor] at present more than 850 feet above sea-level, has not been glaciated, as not a single foreign pebble can be found . . . Briefly, the Drift becomes very thin at 600 feet above sea-level, and disappears altogether above 850 feet.'

On the Lockwood Hills, up to 867 feet, I found a great spread of gravel forming a fringe to a lower area of Boulder-Clay; and at the entrance to Ewe-Crag Slack, Drift-sands and gravels reach the watershed. These gravels yield fragmentary marine shells and many foreign stones, especially Cheviot porphyrites, and out of a small patch of Boulder-Clay on West Rigg at 810 feet, Mr. J. W. Stather obtained the specimen of rhomb-porphry already mentioned (p. 498). Scattered erratics may often be found on the moors above the limit of the continuous Drift-sheet, but except on the Lockwood Hills I found none above, or even up to 850 feet O.D.

The overflows aligned to the Ewe-Crag-Slack overflow are few in number, but of great interest.

On the Lockwood Hills (Stanghow Moor) there is a shallow and rather obscure channel falling eastward into Seavy Sike. It barely indents the 850-foot contour. This carried, for a very brief period, the overflow from a lake at the head of the Boosbeck Valley, into a lesser lake, with which it later became confluent, held up by a lobe of ice that stood against the spur called Moorsholm Rigg (see fig. 15, p. 520). The Moorsholm lakelet was of long duration, for its over-

¹ Mem. Geol. Surv. 'North Cleveland' 1888, p. 66.

flow behind the spur is of considerable magnitude. This channel probably commenced to be eroded at a little above 825 feet, and continued to cut down almost to the 800-foot contour, though the valley now called the Peat Holes is so deeply filled with peat as to conceal the 800-foot contour where it passes. A small projection of the hillside known as Middle Heads, near the Ewe-Crag-Slack intake, is trenched by a small parallel series of marginal channels. The upper one is a little above the 825-foot contour, the next between 800 and 825 feet, and the lowest, perhaps the best marked, runs a little above the 775-foot contour. These belong to the aligned sequence falling to Ewe-Crag Slack; and it is interesting to observe that the single large channel at the Peat Holes is the equivalent in time of these three small overflows. The lowest overflow is at a higher altitude than Ewe-Crag Slack. A period of somewhat rapid retreat of the ice-margin seems to have ensued, and this area was, by means of a series of marginal channels, placed in communication with a great direct overflow at Stonegate, 4 miles to the eastward. Before considering this, I will briefly mention a temporary direct overflow that possesses some features of especial interest.

On the Eskdale side of the watershed near Doubting Castle, just 1 mile east of Ewe Crag, a small patch of gravel occurs exactly on the 725-foot contour. This gravel is well-bedded, and contains foreign stones, such as porphyrite, granite, flint, and basalt. Its position and contents alike render it probable that it has washed over the watershed, and it is seen that it lies in a small valley which rises to a depression in the watershed on Girrick Moor, only 760 feet above sea-level. The actual passage through is a broad swampy tract marked at Danby Peat-Pits. I have probed the peat at many places up through the depression, and found about 8 feet of peat resting on gravel. On the outer face of the hills, a thin covering of Drift extends quite to the watershed. The explanation of these phenomena appears to be that, at the maximum extension of the ice, one lobe of its very much indented front reached for a short time far enough to impound water in a small recess of the hills. The overflow passed over into Eskdale, and the gravel which it carried was arrested at the level of Lake Eskdale (725 feet), the exact height at which the Murk-Mire-Moor overflow commenced its action. This would indicate that the maximum extension of the ice at Girrick synchronized with its farthest advance into the Murk-Esk Valley: such coincidences are, I conceive, neither necessary, nor usual (see fig. 15, p. 520).

The Stonegate Direct Overflow and its Related Phenomena.

I now come to one of the most complicated and difficult problems that has yet engaged my attention. I have already stated that the Cleveland watershed was overridden by ice from the seaward end as far as Stonegate, and the overriding mass not only pushed for $1\frac{1}{2}$ miles up the Esk Valley and formed a

moraine above Lealholm Bridge, but it also extended across the valley and up beyond Goathland. Round the margin of this invading sheet, a deep overflow-channel was soon initiated, running down the Stonegate Valley. This channel, upon the retreat of the ice from the Moorsholm watershed, took the whole drainage from the Lockwood Hills, and probably the Boosbeck Valley, eastward.

The Drift-maps of the Geological Survey show an extension of the gravels on Black-Dyke Moor, for which there is no corresponding overflow. This was laid down at the maximum extension of the ice, and no definite channel would be produced, as Lake Eskdale would be at its highest level (725 feet). The gravel is mapped at an altitude exceeding 725 feet, but below 750.

The first clear indication of a channel to carry drainage from the westward is Hardale Slack, an immense trench cut in the plateau of Roxby Old Moor and running quite through it. This is a typical example of a severed spur. Its upper end cuts through the 700-foot contour, and there is a long stretch of peat-swamp which conceals a deeper channel. (See map, Pl. XXIV.)

A beautiful example of a deserted oxbow is found on the south side of the channel, immediately west of Black-Dyke Slack. It isolates a small conical hill, and was no doubt produced by a temporary forward movement of the ice-front, which compelled the water flowing past it to cut a small 'marginal 'in-and-out' channel round its edge.

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 originated as mere gutters to carry water flowing directly off the ice itself. Their arrangement and disposition is what I have generally found in cases where the ice came quite on to, or over-rode, the watershed.

We may now consider the series of channels carrying the water through to Tranmire Slack, first describing those of the Moorsholm area. Hardale Slack seems to have been a channel formed during or near the maximum extension of the ice, for the marginal drainage of the country from Danby Peat-Holes eastward. There is a fine gravelly moraine, which extends from Great Dinnond through Little Dinnond, Middle Rigg, and Good-Goose Thorn. Flow seems to have taken place along the outside of this moraine, and there is a more or less defined channel all through. It is best seen at Good-Goose Thorn, where its position is marked upon the 6-inch maps by two ponds. At the upper end it lies between 725 and 750 feet, but to the eastward the 725-foot contour is cut completely through.

A slight retreat of the ice-front opened another series of channels in this region. Three small marginal channels cut across a spur of the hill marked 'Water Dittins (B.S.)', above the 700-foot contour, and open into a valley of the same name. The line of flow

Fig. 1C.—Map of the country round Stanghow.

is continued by a valley round an isolated patch of ground at Easington High Moor, whence it passes into Hardale Head by a fine valley at the Nan Stone, each of these cutting the 700-foot contour.

The westernmost channel of which I can be certain is a small one which crosses Smeathorns Road, and cuts sharply the 750-foot contour; it falls eastward into Swinsow Dale, and has already been mentioned as affording an example of 'down-stream dichotomy:' as the ice withdrew to the northward, a new outfall was produced on the northern side of the earlier outfall. Examples such as these are very impressive, for they enable the observer to picture vividly to himself the exact margin of the ice.

Of about the same age is a remarkable little 'in-and-out' channel called Spring-Head Hole, at the edge of Moorsholm Rigg. A lobe of the ice-sheet appears to have stood against the smooth hillside here, and caused the impounded waters of Hare Dale to the westward (as well as all flowing from the Lockwood area) to sweep round the edge of the ice, and excavate a loop in the face of the hill, leaving a central block intact. The cutting of this loop commenced above the 725-foot contour, and continued down nearly to the 700. It is possible that this may belong to the final stages of the Hardale-Slack (Roxby Peat-Holes) overflow.

Near Spring-Head Hole is a singular valley cutting round Haw Rigg, which must, I think, have been shaped by alternate flow to eastward and to westward. The westerly escape was the last, and took place subsequently to the formation of the Spring-Head overflow.

An exceedingly clear and well marked pair of marginal overflows, which I have called the Double (see Pl. XXV), marks a further slight shrinkage of the ice-margin from Moorsholm Rigg. The upper one, marked on the maps by the appropriate name of Hole Skew, is a sharply hooked channel opening out of Hare Dale by a square-cut intake 50 feet above the floor of the valley; it falls rapidly towards its eastern end, and cuts through the 700-foot contour, but not down to the 675. Its twin companion, distant from it about 75 yards, just cuts the 675-foot contour except at the intake where there is a considerable accumulation of peat. It is interesting to observe that the top of the lower valley is immediately below the intake-level of the upper one.

I have not been able to study with sufficient care the country to the north of Roxby High Moor and Wapley, so I cannot say which of the overflows in that area continues the alignment indicated by the contoured maps of the overflows at Moorsholm. The head of Tranmire Slack ends in a great expanse of swampy ground, Tranmire itself, which forms the common head of Birch Hill Beck, flowing northward, and a minute stream that flows down the Slack and joins Stonegate Beck; the two streams actually anastomose at their common head.

The swamp scarcely rises above the 625-foot contour, and I believe that the actual rock or Drift-floor is well below that elevation. If

this be so, it will explain the occurrence of a well-defined overflow-channel at Stanghow, 6 miles away, which cuts the 625-foot contour throughout its course. It occurs in a morainic country, and at one point east of the village it appears to have been choked by a subsequent deposition of gravel. This is the lowest channel possessing an easterly drainage that I have been able to trace in the area north of the Cleveland Hills; and I would particularly emphasize the critical relation of its altitude to that of the Tranmire overflow, which is the lowest breach in the main watershed. Within 200 yards of the intake of this Stanghow channel, and a few feet lower,

Fig. 17.—*Map of the Boosbeck valley, showing the deviation of the stream at Slapcawath.*

we find the head of another valley running through Bushy-Dale Wood with a steep fall to the westward. It cuts deeply into the 600-foot contour (see fig. 16, p. 524). It seems quite clear that in the same way that the direct overflow at Ewe-Crag Slack ceased its operation because of the opening of the much lower Tranmire series of direct overflows, so Tranmire in its turn was abandoned in favour of some overflow to the westward. The steep fall of the Bushy-Dale overflow shows that the main overflow to which it was related was at a low level, and I feel assured that it was into the Vale of York. Other westward-flowing channels exist on the lower slope of

the Cleveland Hills, and the constant westerly aberration of the courses of the existing streams proves to my mind conclusively that in the closing stages of the retreat of the ice in Cleveland, the only escape for the water was into the Vale of York. (Some further deductions I shall draw in my conclusions.) A very notable instance of this aberration is the anomalous behaviour of Boosbeck, which, instead of pursuing its course straight down the great open valley to which it clearly belongs, swerves westward through the gorge at Slapewath to join Eller Beck (see fig. 17, p. 526).¹

The conditions of drainage set up in Stonegate Beck during the maintenance of this overflow are very complex, and it is necessary now to return to the Valley of the Esk to obtain a new set of data.

(5) The Low-Level Phases of Lake Eskdale.

I suspended my description of the Glacial history of Eskdale at the stage at which, by the shrinkage of the ice-lobe which invaded the valley of the Murk Esk, Lake Eskdale became confluent with the Goathland Lake (p. 509). The overflow would now be by way of Fen Bogs, and the lake-level would gradually fall by the cutting of the sill down to its actual level, about 525 feet, or perhaps a little lower. The discovery of the subsequent events proved a great surprise to me. There are along the south side of Eskdale several rock-gorges excavated by lake-overflow, some of which are still occupied by the River Esk,² made in such relation to the moraines or to the open valley as to show that the ice-lobe overriding the northern hills must have persisted here after, not merely the mouth of the Esk, but practically the whole coast-line of Yorkshire down as far as Scarborough, was free of ice.

Now, just as it will, I think, be conceded that a lake-overflow is *ipso facto* proof of a clear fall at or below the level of the outlet, similarly a deviation-channel to avoid a moraine-barrier must have

¹ Since these lines were written I have, with the help of my lamented friend the late Mr. J. A. Ridgway (of Beverley), put down a series of boreholes over this area. Within the great Trammire Slack we made a series of four borings from south-west to north-east, beside the peat-holes near Roxby-Moor House. The first two indicated rock at 11 feet below the surface; the next passed through about 8 feet of peat, and penetrated 4 feet into gravel; and the fourth, beside the stream (on the outer curve of the valley), passed through 10 feet of peat, and stopped in gravel at 18 feet beneath the surface. As the ground-level is about 630 feet, the rock-floor must lie at an elevation below 612 feet.

Another set of three borings was put down on the flat watershed, which is at about 635 feet O.D. Two of these were beside the stagnant drain which connects the northern and southern streams: they were both stopped by something hard, after passing through 5 feet of peat and 4 feet of clay. The third boring, 25 yards to the east of these, gave peat, sand, and gritty clay, and the boring was abandoned in the last material at 17 feet from the surface and about 618 O.D. These observations, so far as they go, are in complete corroboration of the conclusions drawn from the two overflows at Stanghow: namely, that overflow by way of Trammire was possible at 625 feet, but not at 600 feet.

² This fact is referred to by Mr. Barrow in Mem. Geol. Surv. 'North Cleveland' 1888, p. 70.

Fig. 18.—*Contoured map of the Lealholm moraine and the gorge of the Esk at Crunkley Gill.*

been cut below the level of the lowest part of the moraine, while the ice still stood against it. I have mentioned that a moraine, the highest in Eskdale, extends across the valley near Lealholm. The lowest point in this moraine is at most 433 feet above Ordnance-datum; yet there is a pair of channels, giving twofold proof that water was flowing from a diminished Lake Eskdale round the end of the moraine at altitudes exceeding 500 feet.

The highest channel is a small, but very definite overflow, known as Wild Slack, which cuts the southern limb of the moraine immediately south of Crunkley Gill; it is not more than 20 feet deep, but is very well defined. It notches slightly the 525-foot contour, although from the gentleness of its slope I am convinced that the fall was very small beyond this: indeed the Slack dies out at the 500-foot contour. It is just possible that the lake into which this drained overflowed by Fen Bogs, although the facts next to be mentioned render it very improbable.

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 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. 19.—Section across Crunkley Gill and the Lealholm moraine.

It may be objected that a simpler explanation would be to suppose post-Glacial denudation to have removed 100 feet of Boulder-Clay from the central part of the moraine. It appears to me exceedingly improbable, however, that such excessive denudation has taken place, judging by the remarkable perfection in which many small features of the Glacial deposits have survived. Moreover, the small overflow at Wild Slack demonstrates the existence of a constraining mass of ice. Whatever defect or

uncertainty may be found here, is entirely absent from the next case to be described.

About a mile below Crunkley Gill, the steep hillside on the south

Fig. 20.—*Map and section of Sunny-Brake Slack 'in-and-out.'*

of Eskdale is excavated by a very perfect example of an 'in-and-out' channel. Sunny - Brake Slack, the channel in question, is about 75 feet deep, with sharply cut sides and a broad peaty floor falling to the eastward. 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, I think, 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; and at several places scarping is observable, especially in the fields south of Low-Wood Lane, where there is a very pronounced feature between the 450- and 475-foot contours.

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, Pl. XXIV.)

Other rock-gorges, always, as Mr. Barrow has remarked, on the south side of the valley, may be seen at East Arncliffe and Bank Wood, but their testimony is not decisive. They may be due merely

to the impartial cutting of the river into a Drift-filled valley, although that leaves unexplained the coincidence of its invariable preference for the south bank.

The three examples, Crunkley Gill, Sunny-Brake Slack, and Glaisdale, show, I believe, 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 to the southward ?

One of the peculiarities of the Fen-Bog overflow which, at the outset of this enquiry, convinced me of the significance of its features, is that it is the lowest outlet from Eskdale, saving only Whitby Harbour. The 500-foot contour is intact right along the southern watershed until Bay Ness is reached, half a mile from the coast at North Cheek, Robin Hood's Bay. The 400-foot contour extends to about the same distance from the cliff-edge at Hawsker; and the 300-foot contour is unbroken up to within 100 yards of the cliff at Whitby High Light, $1\frac{1}{2}$ miles from the town. There is, moreover, no sign of an overflow-channel at any level from Bay Ness to Whitby Harbour; at the latter place, however, there is a great rock-gorge 100 feet deep running along a line of fault.

It is quite possible that the form of the ice-front was such that a broad way existed, a narrow marginal lake, across the space between Whitby Harbour and the High Light, but I have seen nothing to suggest it; and I think it more probable, taking into consideration facts presently to be adduced regarding the next stage of retreat, that the gorge at Whitby Harbour was 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 broad strip, perhaps 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 retreat in Eskdale here described are indicated imperfectly by a series of moraines. I have not succeeded in tracing any between the Lealholm moraine at Crunkley Gill and the series of successive ridges that descend from the northern moors across Eskdale at Glaisdale. These last differ in composition considerably from that at Lealholm, consisting mainly of sand and gravel, while the Lealholm moraine is almost entirely composed of Boulder-Clay. The difference is probably due to the latter having been accumulated wholly under water.

I have already indicated that there are some signs that, at the period represented by the Wild-Slack and Crunkley-Gill overflows, a large volume of water was entering Lake Eskdale by way of Kildale and West Bank. For; just as a higher level of the lake is attested by the deltaic spread of gravel at Commondale, so a fragment of a lower

delta is found at Hell Hole or Holme Bank, near Castleton. It has been much cut into by the Esk and its tributaries, but at its termination at Hell Hole it extends quite across the valley, except for a narrow gorge-like gap cut by the river through hard rock. There is not much to distinguish this diversion from that produced by a moraine, except the form of the gravel-mass. The surface-level of the delta is about 525 or 550 feet.

It is quite possible that an ice-dam obstructed portions of the lower valley of the Esk long after the stage represented by the Glaisdale moraine; but no definite evidence would remain, as the morainic barriers have not, like the Lealholm and Glaisdale moraines, any gap below the top level of the gorges cut by the Esk in evading them. The Stonegate valley presents some features of exceptional interest, which belong apparently to a transitional stage between the high-level and the beginning of the low-level phases of Lake Eskdale. The head of this valley at Tranmire has already been referred to, but not its intermediate course nor its outfall.

At the lower end of the Tranmire Slack, from its confluence with Hardale Slack the valley is excavated through a flattened floor of gravel, which forms a very notable terrace, especially on the eastern side of the valley—or rather a pair of terraces one above the other. Their structure is admirably displayed in the cuttings of a railway, partly made and then abandoned. The lower terrace about the village of Stonegate is a shelf of hard sandstone in which the stream has cut a splendid gorge, but just above where the road to Whitby crosses the stream, the old railway-cuttings begin, and they show about 30 feet of very coarse gravelly clay, containing so many fragments of Upper Liassic shale as in parts to make up a large proportion of the mass. Blocks of Jurassic sandstone, rounded, sub-angular, and angular, are abundant; some attain a length of 3 or 4 feet. Among the stones are many foreign to the district, of which a list has been published in the Report of the Erratic Blocks Committee.¹ The most noteworthy fact is the comparative rarity of Carboniferous rocks, and the abundance of Magnesian Limestone with botryoidal and other concretionary structures. These gravels continue up the valley above Low Whin. A second terrace at about 575 feet shows a marked rise as it runs up the valley.

The explanation of these features which seems to me at present most satisfactory, is that they were produced as a kind of marginal delta between the hillside on the west and the ice-margin on the east of the valley. The phase seems to coincide with the stage when the Lealholm moraine was being formed. The ice-margin then swept round the angle of Lealholm Moor, and past Hole-i'-th'-Ellers to the terminal moraine. The gravelly material, very imperfectly washed, was laid down alongside the ice in the Stonegate valley, while the flowing water cut a marginal shelf in the face of the hills overlooking Eskdale.

¹ Rep. Brit. Assoc. 1899 (Dover) p. 400 & 1900 (Bradford) p. 345.

Lower down the Stonegate Valley, some features are seen which are connected with the stage of retrocession marked by the lower phase of Lake Eskdale. At Stonegate-Gill Wood, just south of the hamlet of Stonegate, there is a mass of Drift, mainly gravel, but apparently more clayey in its lower part, which has evidently blocked up the original valley and caused a deviation to the western side, where a fine gorge nearly 200 feet in depth has been cut, the lower 100 to 125 feet in solid rock. The fact that this deflection is to the westward, while the southern tributaries of the Esk are thrown to the eastward, is interesting, as it indicates very plainly the position of the ice.

The last chapter in the Glacial history of Eskdale and Northern Cleveland which I have deciphered is very clearly recorded by a series of overflow-channels cutting through the northern watershed above Egton Bridge. The northern face of the hills here forms a great amphitheatre about Ugthorpe and Hutton Mulgrave, and is prolonged in the great spur extending due northward parallel with the Stonegate-Tranmire channel for about 3 miles. On the eastward, another spur runs in a northerly direction. The main watershed rises into a fairly sharp crest, culminating at 850 feet above Ordnance-datum in Kempston Rigg. The central portion of the amphitheatre is broader and lower, and for a space of about a mile is only about 700 feet above O.D. (See map, Pl. XXIV.)

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 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. One or two failed to cut through the watershed, and therefore their share in the system of extraglacial drainage was simply to carry off water flowing down the front of the ice. An example of the latter type slightly notches the watershed on Egton Low Moor immediately above the 700-foot contour.

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.'¹ 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 3 or 4 square miles.

At the easternmost extremity of the Hutton-Mulgrave amphitheatre, just above the village of Aislaby, two small valleys cut through a spur at about 630 and 580 feet respectively. The former of these, Galley-Hill Slack, has much the appearance of a lake-overflow, but so large a volume of water at present descends from springs and surface-drainage, as to suggest the possibility that the valley may be the product of normal drainage. The latter valley displays features so lacking in distinction that, without the corroboration of other members of a related series, I should not venture to include it in my enumeration of Glacial overflows.

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. Landslips frequently take place, and it is evident that the channel is very modern. Mr. Barrow has called attention to this case in his fine Memoir on Northern Cleveland, and has drawn the same conclusion. He says²:—

'The River Esk at Ruswarp is approximately in the centre of its old course and shows no rock. But further north it begins to flow between steep rock-banks, which, near Whitby, are nearly vertical. Its pre-Glacial course was to the west of the town and into the sea, where the cliffs are entirely composed of Glacial deposits. A deep well sunk in this old line of flow went down a great depth without meeting with any rock, but the exact details we were unable to obtain.'

Whether this deviation was due merely to the fact that the old valley was packed with Boulder-Clay and other Glacial materials so as to be completely obliterated, or whether the post-Glacial Esk was, like so many other streams in the district, constrained to take a course along the outer edge of the ice, I am unable to say. Many facts could be cited in favour of either view.

The drainage of that part of the south side of the Esk Valley which lies east of the Murk-Esk Valley must now be considered.

It has already been explained that a lobe of the great ice-sheet at the maximum extension overflowed the northern watershed, and welled up the Murk-Esk Valley as far as the moorland south of Goathland. I have remarked that the evidence that Kempston Rigg was ever completely overridden seems inconclusive, and the phenomena seen on the southern side of Eskdale may perhaps find an easier explanation upon such an assumption, though it does not appear to me to be probable.

¹ An eccentric spelling of the word 'Hole.'

² Mem. Geol. Surv. 'North Cleveland' 1888, p. 69.

(6) Iburndale.

This valley is deep and rather narrow, 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. My observations inclined me at one time to the belief that no portion of the valley south of New May Beck had been invaded by ice, but that opinion has given way before an accumulation of facts, which I think cannot be satisfactorily explained without such an extension.

The position of this valley, opening due northward towards the invading ice, was selected by me at the outset of this enquiry for the *experimentum crucis*. If the obstruction of an ice-barrier produced a lake at Goathland, then Iburndale should similarly show signs of a lake and overflow.

The preliminary examination of contoured maps, which has always constituted the first reconnaissance in this survey, proved the presence of a very suggestive gap in the eastern wall of the valley near its head. The field-observations demonstrated in the clearest manner its character as that of a lake-overflow. (See map, Pl. XXVI.)

The intake is an abrupt notch on the lakeward side. It cuts the 675-foot contour, but the 625-foot contour is not at all indented, and the 650 is but little affected, while a deep, thickly 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. Other characteristics of this valley will be mentioned later.

Sneaton Moor is a long, gently curved crescent of high ground presenting a concavity to the northward. At the maximum extension of the ice, this watershed was completely overridden, and the ice extended forward to the Iburndale overflow. In the stage of retreat, the watershed was trenched by two well-marked lake-overflows, both now streamless where they cross the watershed, and containing a considerable depth of peat. A bench-mark at the intake of one, Nigh-Middle Slack, indicates a level of 676.9 feet, while the other is considerably above 675 feet, though below 700. The watershed here is of exceedingly soft muddy shales of the Lower Estuarine Series, with a few scattered Drift-pebbles; and I infer that no considerable body of water can have drained across, or the channels would have been cut more deeply in such easily-eroded materials.

From Sneaton Low Moor the watershed runs in a general easterly direction, and remains intact and unbroken quite to the coast: therefore the retreat of the ice must have been in such wise that no lakes were formed, for neither direct overflows, nor any sign of marginal overflows can be found.

There are many ways by which this fact may be explained. The retreat may have been so rapid that, though evanescent lakes were produced, the overflows were not cut deep enough to be recognizable: several shallow grooves can, it is true, be seen to cross the watershed, as on the Whitby road. Or, again, the shrinkage of the ice may have been progressive from east to west, so that no lakes could form. Or, as a third explanation, it is possible that marine denudation has removed a coastal region which was channelled by overflows.

A combination of the first and second of these suggestions seems to me to explain the phenomena most fully. The third hypothesis appears to be excluded by the form of the ground at Bay Ness, where the watershed reaches the coast. There are, however, as will be shown later, clear cases in which seaward tracts carrying overflows have been wholly or partly swept away.

(7) The Eastern Coastal Tract.

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, some of which have been ably described and elucidated by Mr. Fox-Strangways. 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 3 miles, drains in a general way down the normal slope of the land into the sea. But, behind this, at a short distance, seldom more than 3, and never more than 6 miles, there runs a great gorge or connected series of gorges (like the intercepting drains of the engineer) which receives all the drainage of the hinterland and carries it away to the southward, and finally westward, through the Vale of Pickering, into the Ouse and Humber drainage. Thus it is that streams, rising within 2 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 many areas.

I shall deal with this region in four sections, corresponding with four natural divisions of the country:—(a) Robin Hood's Bay; (b) Peak to Cloughton, and Hellwath to Harwood Dale and Burniston; (c) Burniston to Scalby; and (d) Scalby to Filey.

(a) Robin Hood's Bay.

Physically, Robin Hood's Bay is the half of a dome-like inlier of Lias produced by a cross-fold at the seaward end of the Cleveland anticline.

The various divisions of the Lias, down to the *planorbis*-zone, are exposed round the shores of the bay; above these come the Lower Oolites, consisting mainly of the Lower Estuarine Series, a succession of sandstone, shales, and coals presenting a surprising resemblance to the Coal-Measures.

The bay is surrounded by a much deeper amphitheatre of high ground composed of the Lower Estuarine Grits, which form a bold, and in places precipitous, escarpment recessed by several alcoves, where streams come, or came down into the bay from the surrounding moorlands. The interior bay is packed with Boulder-Clay to so great an extent, that very few rock-exposures are to be found even in the deeply-cut ravines, and at least at one place, at the mouth of Stoup Beck, the Drift-deposits extend below the beach-level.

An outer fringe of Drift near Kirk-Moor Gate and Latter-Gate Hills consists of sand and gravel heaped up in large mounds.

The pre-Glacial watershed has, in part, been already defined, being on the north-west and north that of Iburndale and Sneaton Low Moor. To the south and south-east, it extended from Peak through Stony-Marl Howes, and thence in a wide sweep, round by Burn Howe and Blea-Hill Rigg, to John-Cross Rigg above Iburndale. The drainage of the whole of this area probably converged on Robin Hood's Bay, as that of the northern segment still does, and the gradients down to the edge of the grit-escarpment were in the main so low as to produce rather the appearance of a plateau than of a ridge. (See map, Pl. XXVI.)

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.

The upper part of this channel has already been referred to, in discussing the overflow of Iburndale. This valley, Biller-Howe Dale, opens upon the skyline at its head in the manner so characteristic of these lake-overflows. On its northern side, in the upper and streamless part, is an abandoned high-level oxbow separated from the main channel by a small hill of the solid rock of the country (see fig. 21). I interpret this to mean that the oxbow was a portion

Fig. 21.—*View looking up Biller-Howe Dale. (The conical hill near the intake is isolated by the deserted oxbow.)*

[From a photograph by Mr. Godfrey Bingley.]

of the first-formed channel, which was overridden by the ice in a temporary advance during which the present channel was cut to such a depth, that, on the recession of the ice-front, any resumption of the first line of flow was impossible. Such cases are not uncommon in the Cleveland area, and especially in the portion yet to be described.

From the point where Biller-Howe Dale makes a right-angled bend to the southward, 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. 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 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 rapidly for a time to a position about which it lingered for a very long period, long enough for many large and deep channels to be cut which are, I think, unsurpassed in the whole Cleveland area.

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 western margin of the ice-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 Foulisike Farm.

The next phase of retreat initiated a line of drainage, second in importance in the Cleveland area only to the great Newtondale gorge: this is the valley, bearing different names in its parts, which I may call the Jugger-Howe Valley. The margin of the ice had withdrawn northward so as to lie upon, or entirely behind, the Sneaton-Moor watershed. The shrinkage to the eastward 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 Iburdale. This new channel, which I may call the Foulisike 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. No stream, but only swamp, occupies the upper part of the gorge.

Simultaneously, perhaps, with the formation of this valley, or possibly of an earlier date, coinciding more with the cutting of Grey-Heugh Slack, a magnificent channel was being excavated along the southern edge of the great amphitheatre near Stony-Marl Howes.

I have been unable to satisfy myself that all the high ground bounding Robin Hood's Bay on the south, which culminates in Stoup Brow (871 feet O.D.), was overridden by the North Sea ice-sheet; but, if so, the phase was a very brief one, and the ice-front broke up into a sinuate outline. The lobe, which was thrust into the upper bay formed by the escarpment of Estuarine Sandstone, would have a strong southerly component of its motion, if one may judge by the general phenomena of a boulder-transport in the coastal tract of Yorkshire; and this conclusion is strengthened greatly by the direction of the few glacial striations observed upon the rock-surfaces. One striated surface has been observed in Robin Hood's Bay by my friends Messrs. H. B. Muff & T. Sheppard,¹ and I had the pleasure of seeing it under Mr. Muff's guidance. It occurs on the top of a hard bed of Estuarine Sandstone at Bay Ness, and the striæ have a direction towards the south. The effect of a thrust in a southerly direction would be to cause the ice-lobe to stand well away from the escarpment at its north-westerly angle, while it would press much more closely against the very precipitous slopes on the south and south-east; so that while in the north-west there would be a considerable lake to discharge by the Foulisike overflow, there would be only space for a series of small narrow lakelets along the southern edge. These lakelets appear to have drained for a long period by means of a marginal channel trenching the face of the escarpment, and attaining at last a depth of about 70 or 75 feet. This channel, about a mile in length, is now occupied in its lower half by a small rivulet, Burn-Howe Beck, but near the intake at Cook House it is streamless.

Two related channels trench the western end of Stony-Marl Howe, and converge before opening into the head of Burn-Howe Valley, near the confluence with which the small stream that they at present conduct doubles back and flows into the Robin-Hood's Bay drainage, while the old course is still traceable as a dry valley.

I am convinced that the Burn-Howe channel continued to operate for a long period, yet not for the whole time during which ice-dammed lakes persisted in the district, as its thalweg falls steadily from the intake at Cook House to within about 600 yards of Jugger-Howe Beck, in which distance it has declined from about 610 or 615 feet O.D. to 525 feet. Beyond that point, however, the slope is much steeper into Jugger-Howe Beck, namely, about 100 feet in 600 yards. The steeper slope represents the more active cutting by Jugger-Howe Beck since the abandonment of the Burn-Howe channel by the Glacial waters.

The recessed character of the grit-escarpment brought about, as

¹ Glac. Mag. vol. iv (1896) p. 52.

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.

Some channels such as I describe were thrown out of action, as soon as the ice shrank well away from the watershed, and lateral communications were opened up. One good example of these temporary overflows is seen running from the cross roads near Evan-Howe farmhouse towards Evan-Howe Slack.

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 overflow of the first of these by Foulisike I have already described. The second, Evan-Howe Lake, was drained 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. There is at present no stream in the upper two-thirds of its length, and only a diminutive rivulet in the lower part; its broad intake is probably at about 535 or 540 feet above sea-level.

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 Foulisike overflow now became functionless. Two of these lesser channels are traceable at Moor-Close Plantation and Chapel Garth respectively. The former has its intake somewhat above 550 feet O.D., and the latter is a little lower. I am unable to explain why the levels should be arranged as they are. If the Chapel-Garth overflow, which is the farthest from the ice-front, were a deep and strong cut, I should be inclined to suggest that it had been re-deepened in consequence of the closure of its rival by a forward oscillation of the ice, but in fact it is a very shallow and ill-defined valley.

The southern lakelet drained by the Blacksmith-Hill overflow, which is a gorge almost exactly comparable in its dimensions with Evan-Howe Slack. It is about 1000 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. This is indicated clearly by the levels—the intake of Burn-Howe Dale is above the 600-foot contour, but the watershed upholding the Blacksmith lakelet for more than half a mile lies below that level. The 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 still stood for a short time against Swallow Head, the spur which bounded Kirk-Moor Lake, for the overflow across the spur at Moor-Close Plantation cuts at its lower end below the Evan-Howe-Slack intake.

A final and, I think, rapid recession of the ice opened some way for the waters round the seaward end of Peak, and perhaps by channels cut in lower grounds of which marine denudation has left no relic; or it may be that some traces exist in the curious undercliffs which have long been among the problems of the geology of the Yorkshire coast.¹

I think it probable that during nearly the whole period of prevalence of the lakes which I have just described, 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.

I must mention two remarkable examples of deserted oxbows occurring in the system of valleys here described. They possess a more than common interest, as they are of opposite types, and prove with unusual clearness the nature of the agency which constrained the drainage in these channels and the radical change which was effected.

A small deserted oxbow in Biller-Howe Dale has already been mentioned. In that case, the old channel was on the 'iceward' side of the more modern one, and I attributed its closure to a slight advance of the ice. An exactly similar, but far finer example is found running behind Brown Rigg—a bold and steep-sided hill dissected out of a high patch of moorland on the east side of the Jugger-Howe Valley. The old channel is very sharply cut; it has a maximum depth of about 60 or 70 feet, and a length of nearly half a mile. At both ends, it opens out on the very precipitous wall of the Jugger-Howe Valley, at an altitude of about 60 or 70 feet above the floor of the valley. (See fig. 22, p. 543.)

The explanation which occurred to me during my examination of the ground, was that this was a portion of the main marginal channel which was produced at an early stage of the ice-invasion, when the maximum extension was almost attained; and that a subsequent forward movement brought the ice-edge across one or both ends of this loop, and caused a new and deeper channel to be cut outside. In this particular case, interesting confirmation of my hypothesis was found in the discovery of a patch of stony clay with erratics on the northern end of Brown Rigg. Also, on a sort of terrace or bench on the face of the Jugger-Howe Valley, a little to the north of the intake of the oxbow, a quantity of gravel was found that extended up the slope to the watershed, which is rather low there.

¹ The undercliff at Peak is largely, I am sure, of origin similar to the Cretaceous undercliffs of the South of England. It is due, that is, to landslipping, as I have observed considerable landslips actually in motion.

The other example of a deserted oxbow is on the western side of Evan-Howe Slack. It is, like the last, of crescentic form, but the crescent is turned in the opposite direction. It is about a quarter of a mile long, some 40 feet deep, and opens on the wall of the main valley at an altitude of about 50 feet. I consider that in this case the main Evan-Howe channel was first formed, and that it was closed by a slight forward movement of the ice, probably the same as that which closed the Brown-Rigg channel. On the retreat of the ice the old channel was still the deeper, and flow along it was resumed.

Fig. 22.—*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.)*

[From a photograph by Mr. Godfrey Bingley.]

Before taking final leave of this section of country, I may just say that the discovery of this complex reticulation of channels cut by the overflowing waters of Glacial lakes, out of a gently-sloping plateau of at present heatherclad moors, impressed me more than any other illustration of the effects of the Ice-Age that I have seen. The necessity for some explanation dependent upon the admission of a great ice-sheet in the North Sea has never appeared to me more imperative; and I earnestly hope that the few distinguished British geologists who still find themselves more impressed by the difficulties—great and real difficulties—in the way of the acceptance of

such an ice-sheet as a postulate in post-Pliocene geology, than with the facts which have led so many to accept it as, with all its consequences, the only possible solution of the problem, will find an opportunity of examining this remarkable region. An easy way to see three of the great valleys, namely, Burn-Howe Dale, Blacksmith-Hill channel, and Evan-Howe Dale, is to take the coach from Scarborough to Whitby. Not only does the main road between the two towns cross these three valleys at their best parts, but it also traverses many fine overflow-channels in the country farther south.

(b) Peak to Cloughton, and Hellwath to Harwood Dale and Burniston.

The very complicated area now to be described extends from Jugger-Howe Beck to the country between the parallel of Peak on the north and the line of the Lindhead (Burniston) Beck on the south. The western and southern boundaries coincide closely with two great pre-Glacial valleys. The area thus enclosed is traversed by two streams flowing along ancient lines of drainage—Hayburn Beck and the nameless stream in Staintondale, which become confluent close to the sea at Hayburn Wyke: their respective valleys were the sites of glacier-lakes. (See map, Pl. XXVII.)

The area is extensively Drift-covered, especially near the coast and near the western boundary. Not even the highest prominences on the northern watershed appear to have entirely escaped glaciation. I have found, as before stated (p. 493), Drift-gravel with various erratics, including flint and Cheviot porphyrites, on the moorland near Green Dyke at about 825 feet above sea-level, and over Stony-Marl Howe. But Pye Rigg, only a mile farther south, appears to be Driftless, though my examination was restricted to the eastern and northern slopes and the summit, and I did not realize at the time that any special significance could attach to the observation.

It seems certain that, for a short time at the period of maximum extension, the ice reached the edge of what is now Jugger-Howe Beck. Whether the ice-margin was entire from Burn Howe to the confluence with Hellwath Burn, or whether it swept in two lobes round Pye Rigg and Stony-Marl Howe, leaving an unglaciated area behind (that is, west of) the high ground, I am unable to say; but the evidence is quite decisive that this condition quickly supervened. I shall assume that the latter was the case, as for the purpose of the present discussion all the special phenomena belong to the stage of retreat. Before the Robin-Hood's Bay watershed was breached by the overflow of Jugger-Howe Beck, a wide valley of normal type descended from Stony-Marl Moor along the Hellwath valley nearly to the site of its present junction with Jugger-Howe Beck; thence, however, its course was continued down the Castle-Beck valley.

When the ice advanced over the country, it thrust across this valley so as to impound the water, which in consequence took an

extramorainic course along the opposite side of the valley, until it cleared the obstruction, at the same time that the overflow from the Iburndale-Robin Hood's Bay area was sweeping down the same line. In this way the Jugger-Howe valley was produced. A well-marked range of gravelly moraine now extends along the verge of Jugger-Howe Beck, which here runs in a narrow gorge from 100 to 130 feet deep, contrasting very strikingly with the broad open

Fig. 23.—Section across Jugger-Howe Beck and Castle Beck, showing the moraine.

valley of Castle Beck which runs beside it (see fig. 23). The watershed separating the head of Castle Beck from Hellwath Beck is not more than 50 yards from the bottom of the deep ravine in which the latter stream flows. At the assumed stage of maximum extension, a small lakelet was held up by ice on the north side of Stony-Marl Howe, and a fine streamless valley with a double intake now comes down to join Hellwath Beck. The altitude of the intakes is about 750 feet. A marginal channel, already noticed in the section on Robin Hood's Bay, also passed down the northern face of the same hill, and carried its drainage into Burn-Howe Dale. The southern ice-lobe appears to have withdrawn somewhat rapidly, its margin retreating simultaneously to the south and the east until it fell behind the north-and-south line of water-parting through Pye Rigg and Hallow Rigg. So soon as this stage was reached, marginal lakes began to be formed. One of these was drained southward by means of a marginal channel, Pye-Rigg Slack, which was joined later by a small overflow behind Moorland House, Rudda Howe. Perhaps to this stage should be referred a small overflow towards Castle Beck which passes through a spur near Thorn Howe. A fine gravel-mound marks its outlet on the southern bank: it cuts the 525-foot contour. A slight shrinkage of the ice enabled the water here to escape in a south-easterly direction down the valley, at present carrying very little drainage, which extends into the Broadlands valley, cutting through a bold belt of moraine in its course. From this point, the retreat of the ice seems to have been very gradual, with long and frequent halts and even some re-advances, repeating in a striking way the fluctuations recorded by the Robin-Hood's Bay series of overflows. The retreat produced two definite lakes—one at the head of Bloody Beck, the principal affluent of the

Staintondale stream, the other at the headwaters of Hayburn Beck. As I shall have many occasions to refer to these, I may designate the former Lake Staintondale, and the latter Lake Hayburn. The Pye-Rigg-Slack and Rudda-Howe overflows were the first effects of the northern lakelet, which formed an aligned sequence with Lake Hayburn and drained into it. The retreat of the ice-margin opened an outlet for Lake Staintondale by a broad col at Rudda Road, where a well-marked overflow, now a swampy gully, exists. It is barely indicated by the 575-foot contour, and its intake may be at about 580 feet. Corresponding with this is an outlet to Lake Hayburn, Cowgate Slack, which commenced to trench the long spur of Hardhurst Moor at about 625 feet. I think that but little cutting took place before a temporary retreat of the ice-front freed a lower col, and the gorge called Hardhurst Slack was cut by the overflowing waters. This channel began operations at or a little below 625, and although it failed to lower its intake to 600 feet (namely 607), it is nevertheless a fine example of a glacier-lake overflow, in its lower part 40 feet deep, with very steep sides and almost dry.

A slight re-advance of the ice closed the intake of this channel, and brought Cowgate Slack again into operation. This continued now to perform the functions of an overflow for a great length of time, and the channel was cut to a depth of more than 50 feet, deepening where it crossed the old watershed to more than 75 feet.¹

The view into the intake of this valley (which is at 580 feet) from the Scarborough-and-Whitby Road near the Falcon Inn is highly impressive. A very diminutive stream now trickles at the bottom, not of sufficient volume to keep the channel clear of vegetation. During the period covered by the formation of Cowgate-Slack Lake, Lake Staintondale cut through a second col in the spur between the two lakes, and an overflow-channel was produced nearly on the line of Tofta Road. It was commenced at an altitude well over 625 feet, but ceased operations at over 600 feet. The unbroken line formed by the 600-foot contour at the Hayburn-Lake side shows that this overflow cannot have operated for long after the resumption of the Cowgate escape, and I therefore conclude that there was a retreat of the ice-front by which the two lakes became confluent.

A further retreat of the ice-front to the eastward began to free the long spur bounding Lake Hayburn on the south, when a point was at length uncovered which was lower than the intake of Cowgate Slack: at that precise level a new channel began to be formed close against the edge of the ice—this is the Ringing-Keld overflow. At first it competed with Cowgate Slack on something like equal terms, but the narrowness of the spur to be cut through, and the further recession of the ice, gave a decisive

¹ I think that it may be possible for some future investigator to correlate the oscillations here recorded with those in the Robin-Hood's Bay area, and even perhaps with that which produced the oxbow at Moss Swang, and the one in Hardale Slack.

Fig. 24.—Section along the watershed, from Cowgate Slack to Hayburn-Wyke Station (Newlands Dale).

advantage to the new outlet, which developed into a large and deep valley, now very swampy in its upper parts, but drier lower down where the steep fall enables a small stream about a foot wide to form. This valley is just a mile long, and falls in that distance 100 feet. It terminates abruptly at 400 feet in a fine terrace, which evidently represents the level of another lake to be presently mentioned. The intake of Ringing-Keld Slack was cut down to about 551 feet.

The further course of the ice-margin is well shown by Oxdale Slack, a magnificent gorge nearly a mile long, and not less than 75 feet deep at the intake, which gashes completely through a bold spur composed of hard and massive grit forming the last limb of the Lake-Hayburn watershed. There is scarcely any more instructive and convincing example to be found in the district than this wild rocky gorge sweeping completely through from side to side of the hill. The cutting was commenced at a little over 450 feet, and it ceases at a little above 375. The form of the contours at the intake shows that a small lake probably received the water from Ringing-Keld Slack and transmitted it to Oxdale Slack.

Another overflow, rather doubtful, and difficult to observe on account of a thick growth of young pine-trees, crosses Cloughton Moor at a slightly lower elevation. But the next marked halt of the ice-margin was at Cloughton-Moor Cottage, where a new overflow was formed which commenced to operate at about 500 feet O.D., and continued to carry the drainage until, by the cutting down of the

intake, the lake-level had fallen to about 460 feet. The valley thus formed is nearly $1\frac{1}{4}$ miles long, with a lengthy stretch of morass in its upper part, a virtually streamless middle portion, and a small rivulet in the lower half. The intake-end of this valley is particularly interesting, as it enables the precise relation to the ice-margin to be defined. At Cloughton-Moor Cottage, within 100 yards of the intake, a transverse section of the valley would show a narrow ridge-like retaining-wall on the iceward side composed of gravel, which extends for a quarter of a mile; and on the opposite side a quarry shows live rock with a cover of only 2 to 4 feet of superficial deposits. These observations are in harmony with the conclusions which might be drawn from the existence of this valley on the brink of a steeply-sloping hillside—they show that the ice must have stood steadily against the gravelly ridge, which I should therefore regard as a moraine, until the overflow-channel was well established. The precise position of the ice-margin at this stage can also be fixed at another point. The hillside bounding Staintondale on the west is steep and straight for a distance of about a mile; and in the neighbourhood of Staintondale village there are numerous scarped shelves at altitudes of about 500 feet down to 475 feet. This feature is specially well-marked through three fields just below the Shepherds' Arms Inn.

These scarps, like those observed in parts of Eskdale and in the Murk Esk, seem to have been produced by water flowing between the ice-front and the hill. I conclude that Upper Staintondale at this stage formed again an independent lakelet.

The next recession of the ice from Cloughton Moor through a distance of about a quarter of a mile cleared a shoulder of the hill about 450 or 460 feet above sea-level. This was a little lower than the intake of the Cloughton-Moor-Cottage overflow, and the lake-waters flowed round the margin of the ice, and commenced the formation of a new channel which passes through the grounds of Moor Lodge, the house itself being in the valley. The continuation of this valley is by a remarkable and intricate set of reticulations, brought about in part by the fact that the retaining-wall of the valley was at one place the glacier itself, and in part also by slight oscillations of the ice-margin, which closed and opened channels in a rather capricious fashion.

The Moor-Lodge valley is in reality merely a gully 300 yards long cutting off a corner of the hill. When it was lowered to about 440 feet, the water, after passing into an ice-bound channel for 200 or 300 yards, cut a notch behind Craven Hill producing a valley of very characteristic form about half a mile long and 25 feet deep at the upper end. A fluctuation of the ice, however, opened a way in front (that is, east) of Craven Hill, and a shallow valley was excavated there which was joined along a tributary cut, by a flow directly from the ice-front.

The southern spur, trenched through by Oxdale Slack, was now nearly freed from ice, but both it and an intervening spur were still obstructed by the ice; and in the northern one near Cloughton-

Newlands a gorge called Stonedale was cut, much smaller than Oxdale Slack, but of the same general type: the cutting was commenced at about 360 feet and continued down to about 315 feet. This carried the drainage at all stages of the cutting of the Moor-Cottage and Craven-Hill overflows. In the earlier stages of the Stonedale overflow, an overflow was cut through the southern spur at Goosedale, but it was small and shallow. At a later stage than that represented by Goosedale Slack, a retreat of the ice permitted escape by way of Cloughton, at first through Stonedale, Holm Hill, and Moor Lane, and later by Little-Moor Slack. A further retreat of the ice freed the eastern edge of Little Moor, and a sharp valley was cut parallel to the hillside, isolating a long hill known as Cober. This hill is morainic at its northern end, while the southern end I found (from a temporary excavation at the residence of the late Sir Frank Lockwood) to be composed of solid rock. This 'Cober' valley has a free opening to the eastward at the upper (northern) end, while it also continues for a little distance to the north-west, where it makes a blind termination at some moraine-like hills. The valley previously referred to, as running from Holm Hill to Moor Lane, has a somewhat similar arrangement at its upper end, where it is closed by the sudden ascent of the valley-head.

The next retreat of the ice produced results of a less equivocal nature—an easterly recession took place which freed a long straight hillside for a distance of about $1\frac{1}{4}$ miles. A new cut was commenced at about 325 feet and was steadily cut down to 255 feet, forming the splendid streamless ravine, Newlands Dale, through which the Scarborough & Whitby Railway now runs. The intake near Hayburn-Wyke Station and Hotel is at about the 250-foot contour. The iceward boundary of the intake is very like that of the Cloughton-Cottage overflow, and perhaps, like it, is composed of Drift.

I may now briefly refer to the strip of country between Stainton-dale and the sea.

A line of morainic gravel-hills forms a strong ridge about Prospect House and Whin Hill, and the western face of this ridge is deeply guttered, as though by water flowing off the ice—a feature that is also well shown farther north at Danes Dale.

At Heathard Point, at Rigg Hall, and to the east of East-Side Farm, are three Glacial stream-channels, but they have all been beheaded by the erosion of the coast; and I am unable to say whether they drained lakelets, or merely, like those just named, flowed directly off the ice. Their magnitude renders the latter supposition improbable.

There remains now in this section of country the great valley of the West and East Syme, extending from Harwood Dale to Burniston. This valley, which is bounded along the south side by the great Corallian escarpment of Hackness and Silpho Moors, is now occupied by two diminutive streams which flow westward and eastward respectively from a low, scarcely perceptible watershed at

275 feet across the middle of the valley. It is quite obvious that the valley was not cut by such runlets as now trickle through it, and we must seek an explanation in the diversion of the drainage by ice-obstruction, in the same way that similar phenomena elsewhere have been explained. Mr. Fox-Strangways has apparently not included this in his explanation of the vicissitudes of the Derwent, but it seems to me clear that whatever cause operated to produce Forge Valley, was equally in operation here to give rise to the Hackness gorge.

The valley of the two Symes extends, as before remarked, to Harwood Dale, and it cannot be doubted, I think, that in pre-Glacial times whatever stream flowed in that valley must have come through to Burniston, and so to the sea. But the pre-Glacial drainage of Harwood Dale would have been less than that which now flows down the valley by all the captured waters from the Robin Hood's Bay area, and so I think would not have produced unaided so large a valley as that of the Symes. If, however, we suppose that the Derwent also flowed in this direction, the difficulty is removed. The Derwent flows in a course nearly parallel to Harwood Dale, to within a little over a mile of the West Syme, then turns eastward as though to make for the sea; then, after following this direction for about 200 yards, it turns again southward, and enters the great Hackness gorge, more than 300 feet deep. At the southerly turn it receives the stream from Harwood Dale that has flowed along the foot of the Corallian escarpment in a cross-channel, which is not only a direct continuation of the valley of the Symes, but resembles it closely in configuration.

I therefore regard the Derwent as the stream primarily responsible for the cutting of the valley of the Symes, while the origin of the Hackness gorge I consider to have been somewhat as follows:—Before the Glacial Period, it was merely one of the many deeply-cut valleys which trench the Silpho and Hackness Moors, but this was one of the lowest. When the valley of the Symes was obstructed by the ice-invasion, the waters of the Derwent were impounded, together with those of the Harwood-Dale stream, and formed a lake which overflowed the rock-barrier about 550 feet above O.D., at the head of the Hackness gorge. With the augmented volume of water poured over, the barrier was cut down to such a level, before the withdrawal of the ice, as to prevent any resumption of the drainage along the old line through the valley of the Symes, which was left by the ice much obstructed with an infilling of Glacial deposits.

There are two features of the Symes Valley which are peculiar and rather perplexing. On the north side of the valley, nearly as far as the transverse watershed, is a great accumulation of gravel in steep-sided hills, elongated in the direction of the valley. The most remarkable of these extend for, say, half a mile about the Thirley-Beck Farm. To the south-east of the farm they are hog-backed hills of gravel some 30 feet high, with sides steeper than I have ever observed in any other British Drift-mounds. To the north-west they are much broader, and enclose a deep longitudinal

hollow in the form of a series of connected basins. The hollows open to the westward, and are closed at the eastern end, so that the enclosing hill has the form of a deep loop. The surfaces of these hollows are strewn with very large boulders of Jurassic sandstone, weighing perhaps from 2 to 10 cwt. each. The whole surface of the hills was no doubt at one time covered with such blocks, for all the drystone walls are composed of them. A section cut through the deposits by Thirley Beck showed a packed mass of large and small boulders. The source of these materials is not far to seek—the excavation of Oxdale Slack would provide enough for a hundred such hills, but their transport and accumulation I find it difficult to explain.

The second singular feature displayed in the valley is a remarkable and gigantic ‘in-and-out’ on the north side of it at the watershed. A valley loops back into the hillside for a distance of a quarter of a mile, then returns to the main valley, so that it winds in and out again behind a central ridge of solid rock more than 50 feet high. The explanation which would ordinarily be given, is that it was a detour effected by a stream to evade the ice-margin, and this I believe it to be. At the same time it is difficult to explain both its situation and the fact that such fall as the valley displays is to the eastward, not to the westward as might have been expected. Upon the latter point, however, it may be noted that two small streams which enter the bend of the loop have been conveyed in an artificial channel across and for some distance down the very level floor to the east. The western limb of the loop is very boggy, and there may be a mass of peat there which perhaps conceals a westerly slope of the floor.

(c) Burniston to Scalby.

This tract of country presents few features of which the interpretation is clear. On the west, the heights of the Suffield-Moor escarpment constitute a possible landward barrier against which glacier-lakes might have been upheld, but the distance is very small, only about $1\frac{1}{2}$ miles. Moreover, above the 400-foot contour, the escarpment is very steep and unindented: no recesses occur in which lakes could be maintained. At and below the 400-foot contour, the country is much more diversified; but a difficulty is encountered which has not previously been experienced—two direct overflows occur, one at each end of the area, and a slight differential recession of the ice-front might open the one or the other.

At the northern angle of the escarpment, a long spur of Drift-deposits continues northward for half a mile, and I regard this as a moraine marking a halt in the recession of the ice. Behind the moraine, a shallow overflow falls to the northward. It shows a later phase in which the channel exhibits what I have termed ‘downstream dichotomy’: the ice-front receded a little, and allowed the overflow-waters to escape down the eastern and inner side of the moraine.

Much moraine-gravel extends from here to Hollin Rigg, but no decisive evidence of lake-overflows is visible. At the southern angle of the escarpment at Scalby Nab a gravel-covered spur exists, of much smaller dimensions than the northern one, but, like it, scored on its outer (western) face by a small gully with a fall to the southward.

(d) Scalby to Filey.

The last tract of country to come within the scope of this paper is that which completes the system of extra-morainic drainage of the Cleveland District on its seaward side. It extends from Scalby to Filey along the coast, and inland from Mowthorpe at the top of Forge Valley to Wykeham in the Vale of Pickering. The physical features of the region are simple—there is a coastal tract of Middle Jurassic rocks backed by a bold escarpment of Corallian rocks, which sweeps round from Mowthorpe by way of Scarborough to Gristhorpe, where it reaches the coast and forms the fine range of cliffs terminating in the natural breakwater of Filey Brigg.

The Corallian rocks dip in towards the Vale of Pickering, but the strike, which is nearly due east and west in the Forge Valley, swings round to a west-north-westerly and east-south-easterly direction near Filey, while in a westerly direction it changes in the opposite sense; the dip-slope is consequently arcuate. Many deep valleys exist in the Corallian rocks which are almost or quite destitute of streams at the present time. Such valleys may have been produced like those in the Carboniferous Limestone, by streams which have subsequently taken to underground channels; or again they may, like the great valleys in the Chalk Wolds, have been excavated by running water during the Glacial Period, when the rocks were all rendered impervious by their frozen condition. It has been necessary to discriminate carefully between these valleys and the abandoned lake-overflows. The Drift-deposits attain a great thickness in the area (in one case noted by Mr. Fox-Strangways, probably as much as 200 feet) in the deeper pre-Glacial hollows. I have found it desirable in this investigation to examine very carefully the extension of the Glacial deposits at high levels on the Corallian rocks: it seems clear that they extend completely over the range from Scarborough to Filey. The great elevated block to the westward of Scarborough—Seamer and Irton Moors—opposed, however, so great an obstacle to the ice, that although the escarpment was overtopped even at its highest part, and gravelly moraine was laid down near the brink to form the irregular range of hills culminating in Seamer Beacon 600 feet above sea-level, yet the western slope was never invaded.

The edge of the ice here can be made out with great precision. Hagworm Hill is a mound of sand and gravel with erratic pebbles, and similar hills range southward to Riggs Head, but I searched in vain the cultivated land immediately to the westward for a foreign pebble—the soil appeared to be entirely the product of underlying rocks.

The pre-Glacial drainage-lines of this region differed in one very material respect from those now followed—the great wide valley of the Sea Cut which passes between the Corallian blocks of Suffield and Seamer Moors was occupied by a large stream, consisting of the confluent waters of the Black Beck, Sow Beck, Kirk Beck, and the stream which flowed down the Hackness Valley before the overflow of the Derwent. It is not improbable that the Sea-Cut valley remained open after the closure of the corresponding valley to the north, that of the two Symes. In that case the drainage of the whole country from Iburndale southward would, after passing into a lake at Harwood Dale, overflow down the Hackness gorge and come through the Sea Cut, but not even then would it obtain direct access to the sea.

An advance of the ice-front to the Row-Brow escarpment near Seamer Beacon would impound the drainage of the Sea-Cut valley, producing a lake, which may (for convenience) be referred to as the Hackness Lake. When the waters rose to about 400 or 425 feet O.D., the lowest gap in the Corallian escarpment, which was at Spikers Hill, would be surmounted, and a large volume of water would flow down the dip-slope of the Corallian rocks towards West Ayton, in the Vale of Pickering. I do not think that any considerable valley existed previously on this line, the contour of the country seeming opposed to such a view.

The line of drainage thus initiated was rapidly deepened and a veritable cañon, Forge Valley, produced, which in the sharpness of its lines surpasses even the Hackness gorge. Some features of the emergence of the Glacial torrent into the Vale of Pickering will be described a little later (p. 557).

An ice-lobe appears to have penetrated far up the Sea-Cut valley, and I am disposed to regard the great mounds of gravel at Thorn Park, close to the Derwent, as of direct Glacial origin; but I do not think that the ice advanced much beyond this point, for there is a second low gap in the Corallian watershed less than three-quarters of a mile beyond the entrance to Forge Valley, and had the invading lobe reached this point, Kimlin Slack would have usurped the functions of Forge Valley. The cutting of the last-named valley must have proceeded, during the maintenance of the ice-barrier, to a depth not far short of 135 feet O.D., as the present watershed of the Drift-obstructed valley of the Sea Cut only reaches that altitude, and a great artificial drain has been cut through from the Derwent to Scalby Beck, by which a considerable volume of water is discharged at normal seasons, and still more when the Derwent is in flood. Unless Forge Valley had been cut as deep as this, the Derwent would have reverted to the old channel.

We may now consider the Glacial drainage of the Scarborough embayment.

The Oolitic escarpment is much indented between the north-eastern angle of Seamer Moor and Wheatcroft, a hamlet about 1 mile east of Scarborough. Many deep valleys existed hercabouts in pre-Glacial

times, and through one of these a great overflow was cut which must have played an important part in the stages of advance and retreat of the ice-front, when small lakelets were held up in numerous re-entrant angles of the hills. This valley is that through which the railway passes from Seamer to Scarborough.

The way in which it expands towards Scarborough shows that it is not, like Forge Valley, entirely the result of Glacial stream-erosion, but that a pre-Glacial valley existed with a northerly outlet. At present it is quite streamless, and an artificial pool,

Fig. 25.—*Borings at Scarborough Gasworks.*

the Mere, occupies a position near the watershed which is roughly 135 feet above sea-level, but there is a good deal of peaty material in the floor, and the actual rock-floor is probably considerably lower.¹

Now, with an outlet at each end, namely, by Forge Valley and by the Seamer valley, the drainage of the recess at Scarborough must necessarily have been very liable to reversal, according as some slight fluctuation of the ice-margin freed the one or the other outlet. This fact was strongly borne in upon me in working over the ground. Lake-

overflows are numerous, but no clear system can be recognized; for, not only may two overflows in the same spur drain in opposite directions, but even one and the same channel bears evidence of flow at one time to the northward to the Forge overflow, and at another southward to Seamer. I will speak of some of these in detail.

The outstanding shoulder of Cornbrash beyond the north-eastern corner of Row Brow, near the village of Throxenby, is deeply trenched by a fine overflow in which Throxenby Mere has been

¹ Since this was written I have been furnished, by the courtesy of Mr. Crawford, manager to the successors of the late Mr. G. Smalley, well sinker, of Hull, with details of three boreholes put down at the Scarborough Gasworks, which are situated about 1500 yards north of the watershed, and stand at a surface-altitude of about 115 or 120 feet O.D. Fig. 25 shows the details of these borings, which furnish complete corroboration of my surmise, and further reveal a very remarkable cliff-like sub-Glacial declivity.

formed by an artificial dam at the eastern end. The western intake however is closed by so slight an elevation, that I think a flow has taken place in both directions, the last being that to the eastward. The cutting of the valley was probably commenced at about 275 feet, and ceased at about 235 feet. Hackness Lake, therefore, stood between those levels for a short time.

An earlier stage is represented by a very small notch 100 yards to the northward, which shows a slight fall in both directions from a central watershed about 385 feet above O.D. This overflow is cut through gravel. The flow seems to have occurred in both directions, the eastern being the last. There is a bench like a beach at the 300-foot contour on the south side of the hill.

To the westward a well-marked marginal channel, with a fall towards Forge Valley, occurs in a gravelly tract above Ox-Pasture Hall. The intake is a little below 225 feet O.D., and it is traceable to a point about a quarter of a mile to the westward, where it cuts the 175-foot contour.

Turning back towards Scarborough again, we find a channel cutting the 300-foot contour behind (west of) Hatterbord Hill. This hill is a portion of a fine moraine, which projects forward from the escarpment at the farmhouse called Row Brow. The channel drained northward towards Forge Valley, and it was modified considerably by subsequent morainic accumulation. On the eastern side of the same hill a long shallow channel exists, which is in my judgment clearly an overflow. It cuts the 225-foot contour, and falls to the south towards the Seamer escape: it is quite streamless. Lady Edith's Drive is another related drainage-valley having an easterly fall. Taken in conjunction with the last, it seems to indicate a recession of the ice-front to the eastward and northward.

Four remarkable valleys cut through the ridge of Kellaways Rock to the eastward. At Northstead the northernmost cuts the ridge with a fall to the westward down almost to the 225-foot contour. The intake has a southerly curvature, probably indicating that the water was flowing from that direction, and this is confirmed by the fact that the hill falls away to the northward. The ice must, as in the former cases, have stood to the northward.

The next, Peasholm Valley, is now occupied by a stream flowing eastward, and, *ipso facto*, I should have concluded that the Glacial drainage of which it is certainly a relic had the same direction. Nevertheless, I am inclined to the opinion that a reversal of the drainage has taken place since Glacial times, mainly perhaps by the action of springs.

The Scalby-Road valley, which cuts well through the 200-foot contour, was formed by a stream flowing westward; the last, the Stepney-Road valley, which also falls westward, cuts through the 225-foot contour.

The group of four I should regard as a connected or parallel sequence; but it is necessary to assume, what is by no means improbable, that there were fluctuations of the ice-front. These fluctuations may not only have closed with an ice-barrier a channel

after it was cut, just as happened to Hardhurst Slack, but may also, as we have seen, have caused an actual reversal of flow.

I think it not improbable that the series was partly cut in order from south to north, the Northstead Valley being the last; but that a re-advance of the ice and second recession completed the cutting of all except the Northstead one, which, owing to its greater elevation, could not have been eroded while lower channels stood open farther south.

In the angle of the Scarborough recess, two overflows of brief occupation may perhaps exist in the cols at Cross Lanes at 307 feet above sea-level, and beside the ancient camp near the Racecourse.¹ In the latter case, two valleys inosculate on a col at 464 feet O.D., but the abandoned head of the southern valley is traceable in the high ground to the eastward. Both these overflows, if overflows they be, drained into the Seamer Valley.

The last Glacial drainage-channel cutting through the Oolitic escarpment from the Scarborough recess, is the fine valley called Deepdale. This valley has many of the characteristics of the Seamer valley, from which it is separated by the bold ridge of Weaponness, culminating in Oliver's Mount, about 500 feet above sea-level.

The present watershed across Deepdale is situated well to the northward of the Corallian escarpment, and from this point a small stream flows in each direction. The watershed, which is in a country heavily covered with Drift, is a little above the 250-foot contour. There is a boulder of Shap Granite within 20 yards to the eastward.

This valley seems to have carried off the drainage of a small lakelet about Wheateroft, but though the valley is of considerable size, the amount of cutting was probably not very great. I do not think that the beheading of the stream by marine erosion would account for its present form and condition. I should consider its sharp outline and precipitous sides to indicate the passage of a large volume of water through it at some date too recent for the comparatively slow erosion of the coast to explain it.

From this point onward to Filey Brigg no definite overflows are traceable, marine denudation having probably carried away a considerable tract of land higher than that which remains.

(8) The Vale of Pickering: Eastern End.

It now remains to consider certain phenomena displayed by the country within the Vale of Pickering, that is, behind the Corallian outcrop.

The closure of the Vale by a species of morainic barrier running through Hunmanby was long ago recognized by Carvill Lewis, Mr. Fox-Strangways, and others; but it has seemed to me very

¹ A re-examination of the ground has rendered me more sceptical as to these gullies.

important to ascertain how far the ice extended westward, and upon this point there was a lack of data. My friend, Mr. J. W. Stather, F.G.S., has kindly placed his extensive knowledge of the district at my disposal, and aided me greatly in attempting to solve the problem.

I have described the occurrence of a range of gravel-mounds on Seamer Moor, which I take to mark the extreme limit of the ice at that level; beyond this, which I consider to be the moraine, Mr. Stather and I found the country absolutely free of Drift. Not so much as a foreign pebble could be discovered at a distance of 200 yards beyond it, even upon lower ground. Outside the moraine the steep slopes of the moorland towards the south are deeply trenched by dry gullies, which appear to have been produced by water flowing from the ice-front. This remark applies especially to the groove running down to Betton Farm.

At Seamer an immense spread of gravel is to be seen near the railway-station, and this may perhaps be connected with the two great gorges, Deepdale and the one admitting the railway to Scarborough. Between the latter valley and the entrance to Forge Valley, the lower slopes of the moors present some noteworthy features. Several valleys occur which run for some distance from east to west, then swing southward: one of them, Waydale¹ for example, cuts across a spur, or rather through two—one a projection of the moors bounding the Scarborough-Seamer valley, and the other a swell of the hill near Waydale House. A very common feature of these channels is that they frequently have a blind head, or there is some transverse mound interrupting the continuity of the thalweg. The features are repeated in certain channels to the west of Forge Valley, which will be mentioned later.

Much gravel occurs in the strip of country displaying these features; but it is intermittent, until a point is reached immediately north of East Ayton and close to the beginning of Seave-Gate Gill. Thence onward to Gallows Hill, between Wykeham and Brompton, the great gravel-bench extends which Mr. Fox-Strangways supposed to be the beach of Lake Pickering. This mass presents an abrupt scarp over 50 feet high overlooking the Vale of Pickering. The brow of the scarp is, at the eastern end, above the 200-foot contour, but it declines westward. The breadth of the terrace varies from less than a quarter up to over half a mile; and its upper edge, where it rests upon the slopes of the hills, falls from very nearly 250 feet (probably about 245) on the south of Forge Valley, to a little over 200 feet near Wykeham. (See map, fig. 26, p. 558.)

The surface-features of this gravel-bench are very noteworthy. Deep valleys come down the dip-slope of the Corallian rocks, of which some (for example, Yedmandale) are destitute of streams; while others, like Beedale and Sawdondale, carry little becks, and one (Forge Valley) is occupied by a small river, the Derwent.

¹ The local name for this valley is 'Marra Mat,' and the stranger will fail to find it as Waydale.

Fig. 26.—Relief-map of the country from Wykeham to Seamer, showing the approximate form of the gravel-bench and the deviation-channels. (Scale: $1\frac{1}{4}$ inches = 1 mile.)

Each of these valleys, when it reaches the gravel-bench, undergoes a sharp westerly deflection; moreover, across the flat top of the gravel-bench, a series of deep channels has been left, forming an almost complete series of links connecting each stream or valley with its neighbour on the west. These channels are generally at a level of 30 or 40 feet above the streams that they appear to have served, and only in two cases, Beedale Beck and Sawdon Beck, are they at present occupied by streams. One very fine example, forming Rushton-Cottage Pasture, the deepest of the whole series, is interrupted by a ridge of gravel which shuts in a deep hollow in a part of the channel.

At the western end, by Wykeham and Rushton, the gravel-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, from the dead-flat floor of which it rises as a bold and picturesque ridge bearing the ancient Wykeham Abbey. This portion of the gravel-mass presents contours quite unlike the scarp of the terrace at West Ayton or Hutton Bushel. A small outlier of gravel lies to the west of the Wykeham ridge, and rests upon a prominence of rock forming Gallows Hill. Beyond this, both terrace and gravel abruptly cease.

Some features of the composition and condition of the gravel may be mentioned. Many sections exist, from which its constituents can be ascertained: I paid particular attention to two gravel-pits at Yedmandale and Hutton Bushel. At the former the beds were of sands and gravels, the pebbles consisting mainly of Jurassic sandstones and limestones, with many Cheviot andesites, some greywackes (probably from the Valley of the Tweed), some jasper, and a few granite-pebbles. I also found fragments of marine shells, among which I identified *Tellina balthica* and *Cyprina islandica*. At Hutton Bushel, in a gravel-pit on the 200-foot contour, rather coarse, horizontally-bedded gravels were exposed, often of the type (so common in Glacial accumulations) which I have termed dry gravels, that is stones packed with open interspaces not occupied by sand or other infilling. The stones were mainly local (Corallian), but there were fragments of Kimeridge Clay, many pebbles of Cheviot porphyrite, and some Magnesian Limestone of the Roker (Sunderland) type, gneiss, and granite. I was informed by the Rev. W. C. Hey that shell-fragments are common in these gravels, and that a great many were obtained in a temporary pit opened immediately east of Forge Valley near East Ayton.

We have here, I think, a body of facts which show conclusively that the Hutton-Bushel terrace is not a simple lake-beach. The pronounced fall of its surface from east to west might, of course, be explained upon the supposition of a differential movement or tilt of the region; but, even if there were no other difficulties remaining, I should hesitate to have recourse to so bold an expedient, except in presence of proof of such a movement of an overwhelming character. There are other, and in my opinion even more weighty,

objections, still remaining. I ought, however, to remark that there are several facts which might be interpreted as evidence of an uplift of the Yorkshire coast since Glacial times, and one which might be regarded as evidence of a differential movement. Dr. W. Y. Veitch¹ has described a raised beach at Cat Nab, near Saltburn, and his observations are confirmed by Mr. Barrow.² The beach is clearly post-Glacial, and is about 30 feet above sea-level. Mr. Lamplugh has described a band of shell-silt in the Speeton cliffs containing estuarine molluscs, as, for example, *Cardium edule* and *Scrobicularia piperata*, with the paired valves in apposition and the siphonal ends upward. They occur at an altitude of about 80 feet above sea-level.

Lastly, I may mention that, whereas at Barnby Dun borings indicate the rock-floor to be at least 170 feet below Ordnance-datum, yet none of the borings made in the bed of the Humber or in Holderness struck a hollow of sufficient depth to afford an outlet to such a valley. A boring on Reeds Island made by Mr. Villiers (of Beverley) in 1888, found rock at a depth of 95 feet from the surface, or about 85 feet below Ordnance-datum. If the evidence regarding the Humber were complete enough to justify the assertion that no such hollow or channel existed, then it might be allowable, or even necessary, to attribute the discrepancy between the levels of the Barnby-Dun Valley and its seaward outlet to a differential movement and uplift along the coastline.

I mention these facts so as to assure critics of my views that the alternatives have been considered.

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 (which I have traced by its morainic deposits on Seamer Moor) passed farther inland, where it encountered the feeble opposition of the range of heights to the south of Scarborough, 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 I regard the great gravel-mass there as 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 valley.

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

¹ Proc. Yorks. Geol. & Polyt. Soc. n. s. vol. viii (1883) p. 221.

² Mem. Geol. Surv. 'North Cleveland' 1888, p. 71.

washed into the space between the margin of the ice-lobe and the hills to form a species of deformed delta, just such as I have observed beside the Findelen Glacier. The stream on encountering the ice would turn away westward towards the only point of escape, Lake Pickering. The lake-level was at this early stage probably about 200 or 225, or possibly 250, feet above sea-level, and the extra-morainic stream would spread its gravels so as to produce a uniform gradient from the floor of the rock-gorge down to the level of the lake; hence the glacier would be margined by a bench of gravel the surface of which fell 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 would, like it, turn along the gravel-bench towards the escape into Lake Pickering. Flood-action would periodically operate to level-off the larger inequalities of surface of the gravel.

In the recession of the ice-lobe, successive avenues of escape in front of the ice would be found by the stream, 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. Irregularities in the gravel-accumulations in time of flood may account for the curious transverse interruptions in the slope of a channel. The most remarkable case of the kind is that of a dry valley extending in a devious course from the inner edge of the terrace at Beedale for nearly a mile, until at Rushton-Cottage Pasture it forms a very deep groove like a railway-cutting, and enters the valley of Sawdon Beck. It is quite clear from its position that this channel at one time carried Beedale Beck round the end of the moraine; and I suggest that the closed hollow in its course, which is surrounded by the 175-feet contour, was produced in the subsidence of a flood which preceded or accompanied a retreat of the ice-front, allowing the present outlet of Beedale by Dingdale to open out. I am bound to say, however, that a simpler explanation might be found in irregular solution of the underlying rock.

When the ice-lobe retreated entirely to the eastward of Forge Valley, the Derwent would debouch directly into Lake Pickering. During some part of this retreat, it seems to me certain that a lateral dwindling of the ice-lobe would permit the river to flow between the elevated terrace of gravel and the ice. The result would be some scarping of the gravel-bank, and a partial redistribution of its materials. Mr. Fox-Strangways has remarked that besides the main terrace, 'there are two minor terraces, not so well marked, at about the 100 and 140-foot contours.'¹ I have not observed these as very definite features, but the explanation which I offer would account for them.

In the recession from Forge Valley, the phenomena of the ice-margin would repeat upon a small scale those already described, and the Marra-Mat (Waydale) and other valleys would be produced. When the edge of the ice had retreated to the spur forming the

¹ 'Valleys of N.E. Yorks' Trans. Leicest. Lit. & Phil. Soc. n.s. vol. iii (1894) p. 339.

western wall of the Seamer-Scarborough valley, a small lake discharged by Waydale Lane, and cut the notch which severs the end of the spur. The peculiar 'dry' condition of the gravel at Hutton Bushel, and the common occurrence of fragmentary marine shells, would be readily explained by the hypothesis here proposed; but it would be exceedingly difficult to explain their occurrence in a lake-beach, whether the lake were closed by ice or by moraine.

It is a singular circumstance that no trace whatever can be found either of beach or of moraine along the foot of the Chalk-escarpment which forms the southern margin of Lake Pickering; but the explanation which seems to me most probable is that there was a deficiency of materials, both for the beach and for the moraine. The supply of moraine may well have been small, as compared with that upon the north side, for the glacier-lobe would have a south-westerly impulse which would bring upon the north side an ice-margin that had rasped a large tract of hilly country, while on the south side comparatively clean ice would come in.

Another important difference between the two sides of the valley is, that on the north side occurs the long dip-slope of the Corallian rocks, which would be drained by many streams carrying gravels. Moreover, on the same side the enormous gorge of Forge Valley yielded its waste to provide deltaic materials. On the south side, the short escarpment-slope of the Chalk would contribute very short torrential streams carrying but little detritus, and no overflow appears to have taken place from other lakes.

IX. SEQUENCE OF THE ICE-MOVEMENTS.

In the section dealing with the Drift-deposits (§ VI, p. 489), I reviewed the evidence which has led me to the conclusion that there were three main ice-movements affecting the Cleveland area—a northern, from Scotland and Northumberland, not previously recognized; a western, proximately from the Stainmoor Pass and the Valley of the Tees; and an eastern, from the North Sea, and more remotely from the area lying to the northward of the Skager-Rack and the Baltic.

It now devolves upon me to endeavour to show the way in which their very complex interactions produced the phenomena that I have described.

The fact that rock-grooves running from north-west to south-east across Hob Hill were disclosed by clearing away the Lower Boulder-Clay—the oldest Glacial deposit of the district—may, I think, be taken to imply that in the country north of the Cleveland Hills the western ice was the first upon the ground. This inference is greatly strengthened by Mr. Barrow's observation that the Lower Boulder-Clay consists mainly of materials from the actually underlying rock or the rocks cropping out immediately to the westward¹; and when it is remembered that one of the rocks borne by this stream, the Shap Granite, is not only dispersed along the whole coastline of Yorkshire, but even far down into Lincolnshire, and

¹ Mem. Geol. Surv. 'North Cleveland' 1888, p. 66.

that at two places, Whitby and Robin Hood's Bay, it has been found *in situ* in Lower Boulder-Clay, no further argument seems to be needed to prove that the earliest stage of glaciation was effected by the Shap-Granite-bearing Teesdale stream. This conclusion is a reversion to an early opinion of mine, which was (I am bound to say) scarcely warranted by the information that I then possessed.

The many and far-reaching assumptions which such a conclusion as this implies, are not realized until we have considered what must have been the condition of the Irish-Sea drainage-basin at the time when a regurgitation of the ice flowing down the Vale of Eden was produced, and the lofty ridges near the headwaters of the Tees were overridden by the reversed flow. The Irish Sea was the common receptacle for ice, not only from the mountains of Wales, the Lake District, the South-west of Scotland and of Ireland, but the extreme state of congestion to which the Stainmoor overflow was due may be said to have resulted from a great influx of ice from the Clyde. Clear testimony to the fact of this influx is furnished by three lines of evidence. The striae upon rock-surfaces in Ayrshire and on the Mull of Galloway show a gradual sweep-round of the ice, so that both the Mull of Galloway itself and the low grounds south and east of Loch Ryan were overridden. Fragmentary shells are found in the Drift about Loch Ryan, which is what might be expected if the ice out of the Clyde had moved over the land; and, finally, the copious dispersal of the very characteristic Clyde rock, the eurite of Ailsa Craig, over the Irish Sea, and especially in the Isle of Man and the North-east of Ireland, proves that the movement was upon a large scale.

Tracing our chain of causation backward link by link, we may, I think, enquire what caused the Clyde ice to attain such proportions; and we find here a clue in the signs which exist down the whole of the eastern coast-line of the British Isles, from the Orkneys to Norfolk, of the pressure of a great ice-sheet, the radiant point of which was somewhere in the neighbourhood of the head of the Baltic. The evidences of this pressure are too well known to need any description here, but among its effects were not only a deflection of our eastward-flowing ice into a northerly or southerly coastwise-flow, but a general shifting of the Scottish line of ice-shedding towards the eastward, so that erratics from the Eastern Highlands were carried over the watershed and out to the west coast.

This effect was felt at the mouth of the Firth of Forth, and though I cannot ascertain that any erratics have crossed the watershed into the Clyde, yet I do not think it can be doubted that, but for the obstruction of the ice-sheet in the North Sea, a much larger proportion of the Highland ice descending into the great Lowland Valley of Scotland would have gone into the North Sea.

If this be granted, then it follows that the Scandinavian ice-sheet was the direct cause of the excess of ice in the Clyde, which by overflowing into the Irish Sea caused the reversal of the ice-flow in the Vale of Eden, and the consequential descent of the Teesdale Glacier to the sea at Teesmouth. It may be objected that the

mouth of the Tees would itself have been closed by the ice-sheet in the North Sea; but I think that the impact of the Scandinavian ice would have proceeded from north to south, and the Firth of Forth (being 100 miles to the northward of the Tees) would have experienced its effects long before they reached the coast of Yorkshire.

The Teesdale Glacier must have continued to discharge into the North Sea for a long period of time, for erratics of Shap Granite are very numerous in the Drift of Yorkshire. Messrs. Muff & Sheppard enumerated 89 of large size, all exposed at the same time, on the foreshore of Robin Hood's Bay, in a distance of about 3 miles. How far to seaward the glacier made its way I am unable to determine, though the 'Rough Ground,' regarded by Carvill Lewis as its moraine, lies some miles from the coast (see p. 496). I am equally unable to decide how far down the coast it made its way when the ice-sheet deflected its flow to the southward, and to what altitude it attained along the northern front of the Cleveland Hills. The dispersal of its characteristic erratics in horizontal and vertical extensions is of no assistance in determining this point, as the dispersal may have been accomplished—and I believe it was—largely by the redistributing action of the later ice-streams.

It might be thought that the high altitude attained by the Lower Boulder-Clay mentioned in an earlier section would have been decisive, as that division of the Drift contains Shap Granite, but I have long felt that the classification of the Glacial deposits was in a very unsatisfactory condition. I am far from being convinced that the 'Lower Boulder-Clay' of the high grounds is the same as that of low levels, for I find a most marked difference between the assemblage of erratics in the whole of the Drift observed by me at high altitudes, and that recorded as characterizing Lower Boulder-Clay at Whitby and Robin Hood's Bay. Whereas at those two localities the recorded erratics belong almost exclusively to the western or Teesdale type, I have found a very remarkable deficiency of Carboniferous rocks at high elevations; while rocks of the northern group (see p. 491), such as Cheviot porphyrites, greywackes, sandstones, and the Roker Magnesian Limestone, are extremely common both in the Boulder-Clay and the Gravel. Scandinavian rocks are also occasionally to be found. My impression is that the differences between the 'Upper Boulder-Clay' and the 'Lower Boulder-Clay' are indicative more of local conditions than of age.

I have not succeeded in establishing any correlation of the lake-phenomena with the period of prevalence of the Teesdale Glacier, nor can I expect to do so, for the evidences of lakes formed during the advance of the ice must in almost all cases be obliterated.

The second phase of the glaciation of Cleveland was the complete diversion of the Tees ice into the Vale of York. This was brought about by the growth of the Scandinavian ice-sheet, and the gradual and progressive obstruction of the British coasts from the Firth downward. Whether the Scandinavian ice ever directly impinged upon this part of the coastline of Yorkshire or not, I will not

venture to say; but if it did, its sojourn must have been brief, and the resolution of the conflicting pressures and movements in the area to the northward soon brought in the third element, the Scottish-Northumbrian ice, as a buffer.

The immense abundance of erratics of Cheviot volcanic rocks has only within the last three or four years been fully recognized by geologists in Yorkshire; and I cannot think that their occurrence can be ascribed to anything short of actual contact with the Yorkshire uplands of ice which came by a fairly direct route from the Cheviot Hills, and probably out of Tweeddale. These rocks can be found at all altitudes, and while they are very common on the coastline, they attain to a far greater prominence in the deposits at high levels. These facts have been impressed most strongly upon me during my work in Cleveland, and my friend Mr. J. W. Stather, F.G.S., has found the same conditions to prevail in Holderness and on the Chalk Wolds. The uppermost fringe of the Drift contains a quite exceptional proportion of Cheviot rocks. I have previously pointed out that, in the high-level deposits, Magnessian Limestone of the type found on the coast of Durham is also exceptionally abundant, while Carboniferous rocks are proportionately rare. These facts are consistent with the view that the Cheviot ice passed over the comparatively small outcrop of Carboniferous rocks of Northumberland and out to sea; then, describing a great curve, re-invaded the land somewhere between the Tyne and the Tees, bringing in stones, such as flints, from the bed of the North Sea, and marine shells in a more or less smashed condition, from the same source. Some of the boulders of basalt and dolerite found in Yorkshire may, not improbably, have been derived from Northumberland. The movement of the northern ice-stream down the coast appears to have been very extensive and protracted, and it may have extended even to Lincolnshire, where the characteristic erratics are found as far south as Horncastle.

Inland, the extension of the Cheviot ice was, in my opinion, coincident with the limit of a maximum glaciation from the Wykeham moraine right round to Scarth Nick; but if it reached to the very edge of the Vale of York, I can see no reason why it should not have even contributed its quota to the great glacier that descended to York. This, however, is a topic which cannot be conveniently discussed in the present communication, but must be reserved for another paper in which I propose to deal specially with the Vale of York.

The direction of movement seems to have been straight upon the northern face of the Cleveland Hills, with a westerly component at the western end, while at the seaward end an easterly direction was imparted by the form of the ground, and especially by the North-Sea depression. I am unable to indicate the position of the point where the westerly passed into the more easterly movement—doubtless it would fluctuate incessantly throughout the whole period of ice-occupation, as one or another of the component elements of the ice-sheet waxed or waned.

The striations on the coastal tract may probably be referred to this period; and, as Mr. Stather points out in his description of the Sands-End striae, they form a consistent series indicating a practically continuous route. The striae at Roker may mark the emergence of the ice from the sea-bed.

The recession of the Cheviot ice took place in a very singular fashion. It appears to have withdrawn from the coastline in regular order from south to north, as the Scandinavian and British ice-sheets shrank back towards their sources; and thus one after another the British river-mouths were freed from obstruction and resumed their normal drainage. But in this shrinkage one most noteworthy irregularity is very clearly indicated. After the almost complete disengagement of the ice from the mouth of the Esk near Whitby, a great lobe still traversed the northern watershed and reached the moraine near Lealholm. It must have crossed the hills with a somewhat westerly tendency, in order to have reached so far up the Valley of the Esk. To this stage we may conceivably refer the abandonment of the Transire overflow, the reversal of drainage across the spur at Stanghow, and the diversion of Boosbeck through the gorge at Slapewath. This last diversion is interesting, as it throws an important light upon the condition of the country to the westward. The ice-front must have stood across the Boosbeck Valley until the Slapewath gorge was lowered below the level of the Drift-barrier across Boosbeck, that is to say, below 425 feet O.D. From this clue it is possible to define some of the further course of the stream; and consequently of the ice-front.

It will be remembered that the overflow-channel into Eskdale by way of Kildale is at an altitude of 580 feet; therefore it is quite certain that there must have been a line of drainage open into the Vale of York. I infer from this that the Teesdale Glacier had already withdrawn behind the Magnesian-Limestone escarpment of the Tees Valley.

The last trace of the Cheviot ice-stream to be found in Yorkshire is perhaps the line of the Drift-hills which fringe the southern bank of the Tees. I do not press this explanation, as I can still perceive difficulties in the way of its acceptance; at the same time, I can see no other way of explaining the presence of this ridge of Drift and the behaviour of the little River Wiske, which flows northward from the Cleveland escarpment to within $1\frac{1}{2}$ miles of the Tees, then turns southward and joins the Swale.

X. THE SEA-OUTLET OF THE LAKES.

One problem remains to be considered, the question of the route by which the waters of Lake Pickering ultimately reached the sea.

There is twofold proof that, while yet the ice-sheet was standing against the coast of Yorkshire as far as Flamborough Head, the outlet of Lake Pickering had been cut down to 130 feet O.D. The moraine across the seaward end has an altitude at its lowest point of only

130 feet; and unless the outlet had been lowered to some such altitude, the Drift-barrier would have been surmounted by the waters of the lake, and a new channel would have been rapidly cut, leaving the actual Kirkham-Abbey gorge as one more example of an abandoned channel. Testimony to the same effect is borne by Forge Valley, which has very narrowly escaped the resumption of its functions by the New Cut. The latter piece of evidence indeed proves that the level of Lake Pickering must have fallen well below this, for the fall of Forge Valley is considerable, and if the head of the valley was at 135 feet the outlet into Lake Pickering must have been much lower.

Lake Pickering in its turn fell into Lake Humber, an extra-morainic lake held up in the great central valley of Yorkshire by an ice-dam at each of its exits. The late Prof. Carvill Lewis, to whom the idea of a glacier-dammed lake in this region is due, represented its extension in a very diagrammatic fashion in his maps, and showed no ice-barrier at the Wash, or even in such a position as to close the mouth of the Humber, but in the accompanying letterpress he says explicitly, 'The mouth of the Wash would be similarly obstructed by the North-Sea Glacier.'¹ With this conclusion I entirely concur. Not only is such a lake necessitated by all the evidence regarding the extension of the ice, but the floor-deposits are present over an enormous area. The fine laminated mud, of identical character and appearance with that of the Cleveland lakes, is widely distributed down the Vale of York, and far southward both in the Triassic valley and in the valley made by the outcrop of the Middle and Upper Oolitic clays in Lincolnshire; but, so far as I am aware, there are no signs of beaches or deltas.

Some other examples of floor-deposits of great interest will demand full consideration on another occasion, and for the present I must restrict myself to the question of overflows. Carvill Lewis boldly carried his rivers across whatever watersheds lay below the supposititious level of his lakes, and showed these streams as broad sounds 10 or 15 miles in breadth. My experience has convinced me that waters of such volume, with such a fall as the positions imply, would cut deep trenches of moderate breadth quite different from those which he imagined. Moreover, a lake would only under the rarest circumstances have two outlets operating simultaneously, and these never at different elevations. Now, Carvill Lewis's Lake Humber is depicted with four overflows at widely different levels. I mention these matters in order to make clear the way for a more satisfactory discussion of the problem, and not merely for the purpose of controverting the views expressed by Carvill Lewis, to whom I owe so much inspiration and encouragement in Glacial geology.

In seeking an outlet for the waters of Lake Humber, I looked—as 'direct overflows' across the Pennine range were forbidden alike by the altitude of the passes and the ice-bound condition of

¹ 'Glacial Geology of Gt. Britain & Ireland' 1894, p. 56.
2 q 2

the western slopes—for traces of ‘severed spurs’ near Derby, by which overflows might have evaded the end of an ice-lobe that deposited any of the sheets of Boulder-Clay described by Mr. Deeley,¹ but without result. Similarly, I failed to find any sign of an overflow from any part of the Trent Valley into the Severn drainage, though there are boulders of Red Chalk, a distinctive East-Coast rock, in the Drift of the Severn Basin. I can, moreover, find no definite traces of lakes in Yorkshire which could have drained at such a high altitude into the affluents of the Severn—all the lake-phenomena of Lake Humber lie below 200 feet O.D., and perhaps much below.

Of low-level outlets two or three exist. The valleys of the Lea and the Churwell would, I think, repay examination, as one or the other, or even both, may have acted as lake-overflows; but these could not have carried off the waters of Lake Humber when, as in its last stages, its level was little above 100 feet O.D. At this altitude, when the Wash was closed, there would be but one channel by which drainage could escape, namely, by the singular valley which cuts completely across Norfolk, and in the central marshy portion of which, near Diss, the westward-flowing Little Ouse and the eastward-flowing Waveney have their common source. The Straits of Dover were, I think, not improbably brought into existence by the discharge of the overflow-waters of our British extra-morainic lakes, and a corresponding but much vaster series lying outside the great ice-sheet across the continent of Europe, as was long ago suggested by Belt.²

In conclusion, I gladly add a few words of grateful acknowledgment of the help and encouragement given on many occasions by Mr. H. B. Muff, B.A., F.G.S., the Rev. J. H. Hawell, M.A., F.G.S., and Mr. J. W. Stather, F.G.S., who have been my companions in many journeys, in fair weather and in foul, over the Cleveland Hills; as well as to Mr. Godfrey Bingley, Mr. Geoffrey Hastings, Mr. Arthur Stather, and Dr. John Kirk for the beautiful photographs from which many of the illustrations accompanying this paper are selected.

EXPLANATION OF PLATES XX-XXVIII.

PLATE XX.

Fig. 1. View of Eller Beck and Fen Bogs from the north-west, showing the ‘intake’ of the Newton Dale overflow-channel and the contrast between the contours of the Eller-Beck and Newton-Dale valleys. The watershed is at the sharp bend of the railway.

2. View looking up Eller Beck from the ‘intake’ of Newton Dale.

PLATE XXI.

Newton Dale at Fen Bogs, viewed from Eller Beck. The stream in the foreground makes a sharp turn to the northward and leaves the great trench untenanted.

¹ Quart. Journ. Geol. Soc. vol. xlii (1886) p. 437.

² Quart. Journ. Sci. vol. xiv (1877) pp. 67-90.

PLATE XXII.

Relief-map of the country between Fen Bogs and Egton Bridge, on the scale of about 2 inches to the mile.

PLATE XXIII.

Fig. 1. Series of sections across Ewe-Crag Slack, with details of the borings in the flat floor of the valley.

2. Relief-map of Ewe-Crag Slack, indicating the positions of the transverse sections and the lines of borings shown in fig. 1.

PLATE XXIV.

Relief-map of the Northern Cleveland Watershed between Danby Beacon and Kempston Rigg, on the scale of about 2 inches to the mile. The south-eastern edge of the map overlaps Pl. XXII, and the western edge joins fig. 15 (p. 520).

PLATE XXV.

Fig. 1. View of the 'Double,' Hare Dale.

2. View looking up Hole Skew, Hare Dale. The flat floor of the valley is perfectly dry.

PLATE XXVI.

Relief-map of the Robin Hood's-Bay area, on the scale of about 2 inches to the mile.

PLATE XXVII.

Contoured map of the country between Hellwath and Cloughton, on the scale of about 2 inches to the mile. 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.

PLATE XXVIII.

General map of the glaciers and glacier-lakes of the Cleveland area, at the period of maximum extension of the ice, on the scale of 2 miles to the inch. The area covered by ice is left unshaded; the lakes are indicated by marginal shading; and the area occupied neither by ice nor by lakes is cross-hatched, to show the relief of the land. The edge of the ice is indicated by a heavy black line. Broken lines are used upon the south and west, as the marginal phenomena have not yet been studied. Contours, as throughout, in feet.

DISCUSSION.

Mr. BAUERMAN said that he desired to thank the Author for bringing before them a close and detailed study of the superficial geology of a district which was comparatively little known. He also commented upon the skilful way in which the cartographical evidence had been arranged.

Mr. CLEMENT REID said that, speaking from his remembrance of the Cleveland district, he was quite prepared to accept the Author's main conclusions. When surveying part of the Esk Valley he was much puzzled to account for the laminated clays referred to by the

Author. The clays were obviously of lacustrine origin, but were entirely unfossiliferous, and no corresponding shore-lines could be discovered. Unfortunately, the necessity for detailed mapping had led to the area being so divided that no one officer of the Geological Survey had had an opportunity of examining both the lacustrine deposits and the deserted outlet of this lake. He heartily congratulated the Author on a most valuable piece of work.

Mr. J. E. CLARK remarked that the fact that many perplexing points were made clear by this suggestive paper, made him very ready to fall in with the views contained in it. As to raised beaches, did they occur to any extent in now existing glacier-lakes? Their rapid fluctuation in level made it seem *prima facie* unlikely. The fact that the ice-fringe fell just short of the northern end of Forge Valley was botanically interesting, as that was, possibly, the only habitat of the May lily in England, an abundant species in Scandinavia.

Mr. HARMER offered his warmest congratulations to the Author. The paper that he had just read was of great importance, and would be of service not only to glacialists working in the hills, but to those of the lower districts also. The way in which the surface of East Anglia had acquired its present form, for example, had always been difficult to explain. The whole region is intersected by valleys, great and small, out of all proportion, both in number and size, to its extent, or to the streams which run, or ever could have run, in them. On such questions the Author's paper threw much light; and it would mark, he believed, a new departure in the study of Glacial geology.

Mr. A. E. SALTER said that he was glad to find that glacial geologists were making more use of contoured maps. He regarded the area under consideration as of the same type as that lying between the Chalk and Oolitic escarpments of Central England, and thought that many of the interesting and complicated phenomena described by the Author could be better explained by regarding the area as being made up of 'cuestas' of Cretaceous and Oolitic strata, separated by lower ground. By the cutting-back of the two escarpments, the subsequent stream-valleys would be truncated, and a system of obsequent valleys formed, which would give rise to the gravel and other so-called 'Glacial' deposits referred to.

Mr. BARROW congratulated the Author on this paper. Having surveyed the area about Robin Hood's Bay many years ago, he recognized at once that the Author's ideas furnished a perfect key to the mode of formation of the narrow dry valleys that constitute so striking a feature of the watershed west of that area.

The Rev. JOHN HAWELL said that he had accompanied the Author in very many of his excursions in the Cleveland district; he had wandered with him through his 'dry valleys,' and assisted him in his boring operations. However convincing the Author's excellent presentation of his conclusions and the evidence on which they were based had been, the evidence in the field was still more strikingly so. He had, himself, resided in the district for the last 22 years,

and during nearly the whole of that time had paid special attention to its Glacial geology ; but very many of the problems which presented themselves were insoluble, until the Author came down and threw a flood of light upon them. He regarded the reading of this paper as marking an extremely important advance in our knowledge of Glacial geology.

The AUTHOR thanked the speakers for the terms in which they had spoken of his communication ; he was particularly glad to have the general approval of Mr. Reid and Mr. Barrow for the views contained in it. With the latter he most fully agreed, as he had himself worked upon the Glacial phenomena of the district for many years without obtaining any enlightenment, before he discovered the clue to their interpretation.

In reply to Mr. Salter, he said that he had exercised the utmost caution in dealing with dry ravines in limestone-rocks, and admitted their glacial origin only in the most patent cases : very few were mentioned in the paper. He dissented entirely from the view that the gorges which he had described were due, as suggested, to protracted denudation of limestone-rocks : they bore every indication of extremely rapid denudation.

He wished strongly to emphasize his indebtedness to the admirable Drift-mapping of the Geological Survey, which had been confirmed by his own investigations in a remarkable way.

Fig. 1.—*View of Eller Beck and Fen Bogs from the north-west.*

Fig. 2.—*View looking up Eller Beck from the intake of Newton Dale.*

[Both the above figures are reproduced from photographs 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 northward and leaves the great trench untenanted.

[From a photograph by Dr. J. D. T. T. T.]

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.]

Fig. 1.—Series of sections across Ewe-Crag Slack, with details of the borings in the flat floor of the valley.

[Thicknesses in feet and inches.]

Scale 0 100 200 300 400 500 600 700 800 900 1000 Feet Vertical Horizontal

Fig. 2.—Relief-map of Ewe-Crag Slack, indicating the positions of the transverse sections and the lines of borings shown in fig. 1.

Scale. 0 200 400 600 800 1000 Feet

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

(Scale : slightly less than 2 inches = 1 mile.)

Fig. 1.—*View of the 'Double,' Hare Dale.*

[The conical hill in the distance is Freeborough.]

Fig. 2.—*View looking up Hole Skew, Hare Dale.*

[Both the above figures are reproduced from photographs by Mr. Arthur Stather.]

SCALE 0 $\frac{1}{2}$ 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.]

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

GENERAL MAP OF THE GLACIERS AND GLACIER-LAKES OF THE CLEVELAND AREA, AT THE PERIOD OF MAXIMUM EXTENSION OF THE ICE.

The area covered by ice is left unshaded; the lakes are indicated by marginal shading; and the area occupied neither by ice nor by lakes is cross-hatched, to show the relief of the land. The edge of the ice is indicated by a heavy black line. Broken lines are used upon the south and west, as the marginal phenomena have not yet been studied.