

ALLUVIAL DEPOSITS AT WOODLESFORD AND ROTHWELL HAIGH,
NEAR LEEDS.

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Woodlesford is situated about six miles south-east of Leeds, and is built chiefly upon the south side of the River Aire on a slope of Coal Measure shale with the Thornhill Rock forming the high ground. Immediately to the south-east of the town, the valley of the Aire opens out considerably, and, stretching as far as Methley Grange—a distance of three miles—and occupying all the low ground at the junction of the Aire and Calder is found the alluvial deposit. The area covered by the alluvium is about two and a half to three square miles. It is marked upon the 1-inch Geological Map as chiefly Second River Terrace gravel, with two patches near the Aire and one near the Calder of First River Terrace. On the northern bank of the River Aire at this part, only the First River Terrace is marked, and that only as a thin fringe not more than half a mile and generally less than a quarter of a mile wide. On the south side of the Calder the Second River Terrace is again found, but only in small detached patches.

Messrs. Henry Briggs, Son and Co., wishing to work the Silkstone and Beeston Seams in the northerly portion of their area, decided to sink new shafts somewhere between Spencer Pit at Newmarket (a little south of Rothwell) and Woodlesford. There were several projects, but a consideration of railway and canal facilities, trade with Leeds and with shipping centres, such as Hull and Goole, pointed to a site near Woodlesford as being the most desirable. The next business was to examine thoroughly the country around Woodlesford from a mining engineer's point of view in order to settle on a definite site for the new colliery. This involved a consideration of the country with regard to the following points:—

- (a) Topography and surface contours. This is necessary because the expected coal must be got cheaply both on to the main line of railway and the canal.



Photograph by]

View of the cutting for sidings at Water Haigh Pit. The water just covers the eroded surface of the Coal Measures—here dipping deeply east. The section on the right shows sand overlain by gravels and sands. The plain beyond is of laminated clay. The picture gives an impression of the 50 ft. "river terrace."

[Godfrey Bingley, Leeds.

Proc Yorks. Geol. Soc. Vol. XIX, Plate XXVII.

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- (b) Space for the laying out of extensive sidings for full and empty trucks, and for the surface buildings and equipment.
- (c) Drainage of all surface waters and of the water which may possibly be met with underground.
- (d) Ease or difficulty of sinking the shafts due to water, faults, and subsidence caused by old workings, etc.

After due consideration of these points a site between the railway and the canal, exactly across the railway from the site finally selected, was more closely examined. This gives ready access to both railway and canal, but it was found unsuitable as not affording space for siding accommodation, and it would further have necessitated the formation of very high railway embankments to deal with the coal by gravitation, and to effect a railway connexion with the main line. On the south west side of the railway, however, is a flat tract of ground bounded on the river side by the 50 ft. contour, and marked as Second River Terrace gravel on the geological maps. This stands about 20 feet above the ground first selected on the other side of the river, which is the First River Terrace. A section taken across the valley at right angles to the railway is like a shallow saucer with the canal and river at the lowest point. The embankment which carries the Midland Railway passes down the centre, and to approach this height at ground level it is necessary to work from the Second River Terrace.

The next question was whether much difficulty would be experienced in sinking the shafts for the colliery through the alluvium. Obviously at any point low down near the axis of the valley there would be much water in the alluvium to contend with, and there was justifiable hope that at any point away from the axis the alluvium would be thinner as a consequence of the slope of the old valley before it was infilled. This slope would determine the direction of flow of the ground-water, whereas the direction of flow of the surface-waters is, of course, determined by the present outline of the surface. Away from the axis, therefore, the alluvium tends to be less water-logged than nearer the centre.

Next, with regard to subsidences caused by old underground workings. The workings in the Haigh Moor seam—at a depth here of only 67 yards—extend from Spencer Colliery almost to the Midland

Railway, and run parallel with the railway at a distance of 150 yards. It was, therefore, possible to draw a line east of which no further subsidence might be expected. This question of subsidence due to coal workings was of great importance, because of the desirability of having good foundations for the surface equipment, especially head-gears, winding engines and boiler chimney. The next point was so to fix the site in this stable area that the curves to the main line and canal would be suitable for the traffic, and so that the minimum amount of embanking and excavating would be necessary to lay down empty, screen, and full sidings. This led to a line parallel with the Midland Railway being fixed. West of this line no surface buildings were permitted, and no embankments higher than the present Midland Railway embankment.

The consideration of all these questions fixed the line for the shafts and for the sidings along which the gravitation from north-west to south-east was decided on. In this way an embankment became necessary on the north-west end of the site, and a large excavation at the south-east end. It was in the making of this excavation, and in excavating the soft ground on the north-west to build up the embankment, that the extensive sections in the alluvium were exposed. These points in connection with the choice of the site have been rather fully dealt with as affording an excellent illustration of the importance of Geology to the mining engineer in all his undertakings, even before a sod had been turned.

The work was carried out under the direction of Mr. Isaac Hodges, F.G.S., and most of the information contained in the above description was obtained from Prof. E. L. Hummel, who was at that time engaged on this work. The first step was to put down a borehole to strike a road in the Haigh Moor seam from Spencer Colliery. The object was to test the accuracy of the plan of the workings, to prove the strata down to this depth and to gain some knowledge of the quantity of water which would be met with in the sinking. The borehole passed through alluvium, and then filled with water, but boring was continued until the underground road was pierced, when the water poured down into it and the hole was then plugged up. Digging operations on the shaft site soon revealed the nature of the material making up the alluvium in much surer fashion than the borehole had done. At No. 2 shaft, the section record was :—

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							<i>ft.</i>	<i>in.</i>
Surface soil	1	0
Brown laminated clay	3	8
Sand and loam	7	0
Blue laminated clay	4	6
Sand (sharp)	..	..	..	..	..	..	3	10
Sand (dark)	..	..	..	..	..	..	0	4
Sand (running)	.	..	..	..	..	..	11	10
Marl, clay and boulders	..	..	..	..	..	..	1	0
							<u>33</u>	<u>2</u>

The Sand at the bottom, called "running sand," carried vast quantities of water, and gave great trouble in the sinking operations.

A typical section was that which was exposed in excavating the alluvium to build No. 3 Engine House :—

							<i>ft.</i>	<i>in.</i>
Surface soil	..	..	..	..	..	..	1	2
Brown laminated clay		..	..	..	..	..	5	0
Sand and loam	..	..	..	..	..	..	3	2
Strong, slaty brown laminated clay	..	..	..	..	..	..	5	10
Gravel	..	..	..	..	..	..	1	8
Sand	..	..	..	..	..	..	3	8
Black sand with manganese dioxide	..	..	..	..	..	..	2	8
Total depth of foundations	..	..	..	..	..	..	<u>23</u>	<u>2</u>

The following was the succession of the beds in the excavations made to the north-west of the shafts to obtain material for the embankments :

							<i>ft.</i>	<i>in.</i>
Surface soil and poor clay with pebbles	..	..	..	..	..	..	3	0
Brown finely laminated clay	..	..	..	..	..	..	2	0
Gravel with large pebbles	..	..	..	..	..	..	0	6
Fine yellow sand (current bedded)	..	..	..	..	..	..	2	0
Gravel (coarse)	..	..	..	..	..	..	1	6
Fine clayey sand	..	..	..	..	..	..	1	0
Banded sand	..	..	..	..	..	..	2	6
							<u>12</u>	<u>6</u>

The height of the solid rock at the north-west end of the excavation, where no alluvium is found, is 71 above O.D., and at the engine house, 44 ft. above O.D., which gives a fall of 27 ft. in about a quarter of a mile. The upper laminated clay can be traced from end to end of the site, but the lower laminated clay commences a little north-west of where the shafts are situated, and is found right to the south-east end of the excavations. The presumption is that it continues still further to the south-east.

PETROLOGY OF THE DEPOSITS.

GRAVELS.

The pebbles of Coal Measure sandstone and grit were very variable in size, the largest being about $6 \times 3 \times 2$ ins. of Coal Measure sandstone. Ironstone nodules of a flattened type—evidently from the Coal Measures—occur in great numbers, while fragments of chert, often cuboidal in form, were by no means rare. The pebbles were somewhat irregularly laid, but there was a general tendency for them to lie with their long axes north-west and south-east, parallel to the present course of the River Aire. The gravel, when treated with dilute hydrochloric acid, showed a brisk effervescence, and this was found to be due to small fragments of limestone and calcite in the finer material intermixed with the gravel. Small pieces of grit and Coal Measure sandstone effervesced slightly, and seemed to be more or less impregnated with calcite. The heavy minerals and general mineral composition of the finer material was found to be identical with the sands associated with these deposits, and do not call for a separate description.

SANDS.

The thickness of the beds was very variable, as the sections show, and the current bedding very pronounced, the general direction indicating deposition by water flowing south-east.

A microscopical examination of the sands shows the size of the grains to be very variable, the pieces of grit and sandstone being the largest. These were distributed irregularly through the sands. The fragments and minerals present (neglecting the heavy minerals to be named later) included sandstone, ganister, grit, chert, coal (occasionally forming bands), limestone, ironstone, quartz, felspar and mica. This is just such an assemblage as would be yielded by the rocks

occurring in the basin of the River Aire. The quartz showed the development of new crystal faces just as it so frequently does in the Millstone Grit: the felspar was quite fresh and was extremely abundant in some layers. Some of the bands of sand were coloured black in consequence of the presence of manganese dioxide, while other bands were deeply stained by the oxides of iron.

In a brief account *of these deposits given in 1911 to the Leeds Geological Association, it was stated by the authors that very few garnets and zircons were found in these sands. The sands had then only been examined in bulk under the microscope, and no separation of heavy minerals had been carried out. This has since been effected by means of a Sollas bottle and Sonstadt's solution, with the results given below, the minerals being named in the order of their abundance. Sand from different horizons and various parts of the excavation have been examined—including the sand mixed with the gravels—and no perceptible differences have been made evident, except that there was a greater abundance of garnets in the sands from the gravel beds :—

- (1) Garnet, in abundance in some of the beds.
- (2) Zircon, very abundant in all separations.
- (3) Leucoxene, often with ilmenite in the interior and anatase or rutile as secondary outgrowths.
- (4) Tourmaline, chiefly brown, but blue and purple also occur.
- (5) Monazite, several grains in each separation.
- (6) Barytes, a few grains in the gravels.

There was often a quantity of clay-ironstone present. Xenotime is possibly also to be added to the list, as many grains were found resembling zircon except in the fact that they were pink in colour or clouded.

These minerals are in all respects similar to those found in the Millstone Grit and Coal Measure sandstone and shales, and will be fully described in my paper upon the Millstone Grit of Yorkshire.

CLAYS.

As shown in the section exposed at the engine house, two beds of clay occur, separated by a varying thickness of sand and gravel. Whilst

* “Alluvial Deposits at Woodlesford,” by A. Gilligan, B.Sc., and E. L. Hummel, B.Sc. *Trans. Leeds Geological Assoc.*, pt. xvi., p. 24.

the base of the top bed of clay maintained a constant horizon the top of the lower bed of clay, which was exposed at the end of the excavation, was undulating and, of course, the sand and gravel separating the beds increased in thickness where the lower bed of clay was thinner. This would point to contemporaneous erosion of the lower clay by a stream which shifted its course.

The most striking character of the clays was the fine lamination which they showed when the spades of the workmen made a clean

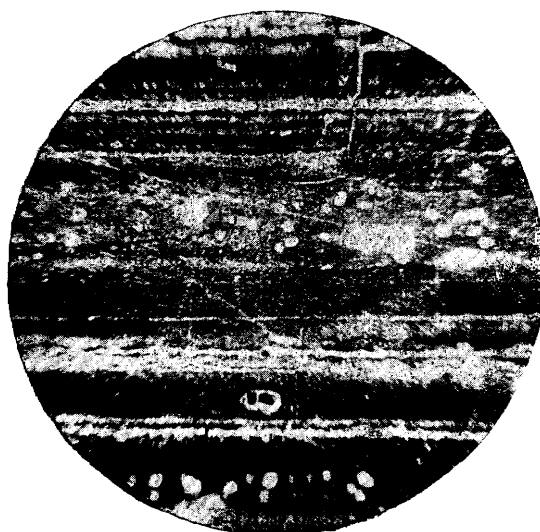


Photo: A. Gilligan]

[X 15.

Photomicrograph of the
UPPER LAMINATED CLAY OF WOODLESFORD.

vertical cut. The alternating layers were light brown and dark brown in colour. The number of laminæ varied from 90 to 130 to the inch so far as they can be counted with a binocular mineralogical microscope, but observations upon dried specimens of the clay show that many of the laminæ which had been counted as one split up into two, so that the number given above would have to be increased. The

dark brown laminæ appear to be very fine grained with a few grains of quartz and mica. The mica is variable in quantity, being most abundant when the brown lamina is thickest. The quartz grains are exceedingly small and angular. The light brown laminæ are much more open in texture and usually somewhat coarser than the dark laminæ. One milky looking grain looked very like a piece of calcite with rhombohedral outline, and when a drop of hydrochloric acid was placed upon it a brisk effervescence took place, showing that the diagnosis had been correct. Following this up by testing other grains, it was found that calcite was present in some quantity in all the light brown layers. If a piece of the laminated clay be taken and a smooth face prepared perpendicular to the laminations, and then a brush dipped in hydrochloric acid be drawn across the laminations each light brown lamina effervesces briskly while each dark lamina is unacted upon. Further reference to this fact will be made in the Appendix, where other laminated clays are also described.

It was also found that each bed of clay had its laminations completely destroyed by penetrating rootlets in certain layers, and in many cases a cast of the hole caused by a rootlet which had decayed had been made in calcite. Some of these were separated and examined, and found to be hollow in each case while the branching of the minute rootlets had been perfectly preserved. When dissolved in dilute hydrochloric acid, only a slight deposit remained showing them to be almost pure calcite, with only a very slight admixture of clayey material. This destruction of the laminæ by penetrating rootlets is interesting in the light it throws upon the absence of bedding shown by true under-clays of the Coal Measures. An excellent demonstration of the fact that the rootlets had actually destroyed the laminæ was afforded at Rothwell Haigh. The washings from sand had been allowed to settle in a pool, where they formed a laminated clay. Upon the dried surface of clay, clumps of grass were found growing, and on digging these up it was seen that the clay penetrated by the fibrous rootlets of the grass was without laminations, though laminations were distinct where there had been no growth of vegetation.

Scattered through the laminated clay, especially in the top bed at Woodlesford were concretions of practically pure carbonate of lime of very irregular shape, reminding one of the "race" in the Thames Valley brick earths. A careful search was made in the clays for traces

of organisms and concretions, but beyond the rootlets mentioned above nothing was found.

Looking at the 1-inch Geological Map it is seen that Oulton Beck meanders across this deposit of alluvium from west-north-west to east-south-east, and it occurred to me that this beck may have in some measure contributed the material which is now found here. The deposits are undoubtedly of deltaic origin, laid down in a lake or pool, and are not such as are ordinarily formed by rivers in such a part of their course. The lacustrine conditions may have been due to the blocking of the mouth of the Humber by the North Sea ice at one stage of the last Glacial period. This ice held up a great lake in the central valley of Yorkshire. As Professor Kendall* points out, the presence of finely laminated muds is indicative of lacustrine conditions, and such clays were present in the great system of lakes which he proved to have formerly existed during the Glacial period on the northern flanks of the Cleveland Hills and in the Vale of Pickering, which latter in Glacial times was a lake receiving practically all the drainage of the Cleveland area. In the Vale of York itself, these laminated muds or clays also cover a very large area, and are found to have exactly the same characters as these at Woodlesford.

How are we to interpret the presence of the two clays with the intervening sands and gravels? The phenomena must mean either that the level of the lake was lowered after the formation of the first clay and that in consequence the rivers could sweep out their coarser material further than previously; or, that there was an increase in the carrying power of the water caused by uplift of the source or an increased volume of water. The irregular surface of the lower clay points to the former explanation, and to the river or stream having meandered over its surface after its formation.

As stated above, Oulton Beck suggests itself as a likely vehicle for the conveyance of some of the material in this delta, and support is given to this view by the fact that it is seen to cut through or rather pass between two very large patches of sand and gravel capped by laminated clay and boulder clay. These occur at a height of 175 to 250 ft., capping the high ground which forms the spur between the

* P. F. Kendall, *Proc. Yorks. Geol. Soc.* Vol. XV. pt. 1, pp. 38-39.

Rivers Aire and Calder. The material at Woodlesford would represent the redistribution of these high level gravels by Oulton Beck. There is evidence also of a diversion of Oulton Beck, which flows south-east at first, and approaches within a mile of the Calder, which it probably formerly entered. But instead of doing so, it now turns due north at Lofthouse Gate, turns east again at Rothwell, and flows between the gravel patches, where it occupies a valley quite disproportionate to the present stream. This diversion could well have been caused by the ice which Mr. Lower Carter* believed to have dammed up the Calder and formed its valley into a lake. In fact, this seems to be the most reasonable suggestion.

DEPOSITS AT ROTHWELL HAIGH AND OULTON.

These were described in 1905 by Mr. E. Hawkesworth in the *Proceedings of the Yorkshire Geological Society* (Vol. XV. p. 456), to which reference may be made for the general phenomena and for accounts of the types of pebbles which occur. One remark, however, with regard to these seems necessary, viz., that a careful search has yielded no igneous rock, and in many visits to the similar gravels at Newlay, I have been unsuccessful in finding even the smallest fragment of igneous rock. This is the more remarkable since in the *Memoir of the Yorkshire Coalfield*, 1878 (p. 779), "trap and flesh-coloured granite" are recorded in the Glacial deposits at Whinmoor, north east of Leeds. I have also carefully searched the new exposures made on the south-east side of the Rothwell Haigh deposits—where a very coarse gravel is found—but without success as far as igneous rocks are concerned. Particular attention has been given to the Rothwell Haigh patch of gravel, and many points of interest have presented themselves which will amplify the description and record given by Mr. Hawkesworth. The boulder-clay which was mentioned in the paper on "The Glaciation of the Bradford Area" by Messrs. Jowett and Muff, (*Proc. Yorks. Geol. Soc.*, Vol. XV. p. 193), as having been found at Rothwell Haigh in making drains, is to be seen at the top of the section near the John o'Gaunt Inn, and though every glacialist would at once recognise it as boulder clay, it is satisfactory to note that scratched boulders have been found in it, both by Prof. Kendall and myself.

* W. L. Carter, *Proc. Yorks. Geol. Soc.*, Vol. XV., 1905, p. 434.

These are usually of Carboniferous limestone or fine grained sandstone. Below the boulder clay is found a bed of finely laminated clay, and this calls for further description. The bed is best seen on the south side of the gravel pit. Indeed, it is hardly seen properly on the north side as the laminations have been almost completely destroyed, for it is not there capped by boulder clay. It is redder in colour than that found at Woodlesford, and contains fewer laminæ, but it is in such a crumpled condition—no doubt as a consequence of its being over-ridden by the ice which deposited the boulder clay—that it is difficult to count the laminæ. Towards the bottom the clay is much bluer, as is usually, of course, the case, as a consequence of the oxidation of the upper part. At the eastern end of the section the boulder clay cuts out the laminated clay and rests directly upon the sand. As recorded previously,* blocks of Magnesian Limestone are found embedded in this laminated clay. The largest seen in situ—which yielded *Axinus* and *Turbo*—was about 1 ft. \times 10 in. \times 7 in., but the largest seen in the pit and evidently derived from the clay, as some was found adhering to it, was 2 ft. 4 in. \times 1 ft. 4 in. \times 1 ft. 2 in., and was a hard crystalline mass with well-marked bedding. A peculiarity is observable in the distribution of these Magnesian limestone masses and pebbles. They are fairly common in the lower part of the laminated clay, but most common about the middle just at the junction of the blue lower and brown upper clay. No Magnesian limestone has so far been found in the boulder clay, nor in the sands and gravels below the laminated clay, unless some of the chert pebbles have been derived from such a source. In the *Memoir on the Yorkshire Coalfield* (p. 779), chalk is recorded among the pebbles occurring in the drift at Whinmoor, and some of the masses found at Rothwell Haigh are as white as the chalk, but a microscopical and chemical examination of one such piece proved it to be a magnesian limestone containing practically no iron or manganese. The mistake could also be forgiven anyone who imagined some of the chert pebbles to be flints derived from the chalk, but I am of opinion after comparing them with chert from the Magnesian limestone that that is their source.

Irregular concretions of carbonate of lime occur as in the laminated clays of Woodlesford, and the action of hydrochloric acid on the different laminæ is the same. Some of this clay was tested for heavy minerals,

* *Trans. Leeds Geol. Assoc.*, pt. XVI., p. 31.

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and also to see whether the carbonate of lime was present as original fragments of limestone or calcite, or as a secondary mineral. The heavy minerals yielded were the following :—zircon, garnet, leucoxene, rutile and tourmaline, named in the order of their abundance. One or two very small grains may be monazite, but of this I am not sure. When the heavy liquid with which the separation was effected was reduced to sp. gr. 2·7, it was found that a large number of the grains which came down were of rhombohedral form with the boundaries very sharply defined, and also showing zonary banding. In addition, masses showing a radial structure and giving a faint black cross were fairly numerous as well as a few groups of sharp pointed crystals which on closer examination with a high power objective, were seen to be scalenohedra of calcite. Here, then, is the explanation of the cause of the effervescence, and a further test showed that the calcite had been deposited in the more porous layers which gave the effervescence in the tests before described.

Below the laminated clay is sand about 15 ft. thick. It shows current bedding with a prevalent direction from north-west to south-east. The sand is noticeably coarser in the bottom part than near the top.

PETROLOGY OF THE SANDS.

The description already given for the sands at Woodlesford is applicable to these except that the manganiferous patches are absent, or nearly so, and there is a greater abundance of coaly layers. The material making up these sandy beds are just such as would be yielded by the rocks occurring in the valleys of the Rivers Aire and Calder, and of these the Millstone Grit has been by far the most important contributor. When the sands are treated with hydrochloric acid there is a slight effervescence.

Percentages of various grades :—

Weight of sand taken	=	465·0	grams.
Stopped by 10 mesh	=	11·2	„
30 „	=	50·3	„
60 „	=	223·8	„
90 „	=	127·6	„
Through 90 „	=	51·5	„
		<u>464·4</u>	

The slight discrepancy is due to the material sticking in the meshes and adhering to the sides of the sieve.

The material which was greater than one-tenth inch consisted of pebbles of sandstone, clay ironstone, ganister, chert and grit, named in the order of their abundance. Separations of the heavy minerals with liquid of sp. gr. 2.8 yielded the following in order of relative abundance :—zircon, abundant in all separations, leucoxene, garnet, rutile, tourmaline, monazite, and anatase.

These are of exactly the same type as those found in the Millstone Grit and Coal Measures. Whilst the list is not a long one, the actual amount of heavy minerals is rather large. As in the separations made from the Millstone Grit and Coal Measures almost the whole of the heavy minerals are found in the material which has passed through the 90 mesh, and is less than .01 inch as actually measured with the micrometer. The exceptions to this in some of the separations were the garnets and leucoxene which were found in notable quantities in material of grade which passed the 60 mesh but did not pass the 90 mesh.

ORIGIN OF THE DEPOSITS.

In the description given of these deposits in the *Memoir of the Yorkshire Coalfield* (pp. 783 and 784), they are spoken of as river gravels of considerable antiquity, formed when the stream was flowing at the level on which they now lie. But, as pointed out by Mr. Hawkesworth in the paper already cited, the problem cannot be so easily dismissed. In the *Memoir*, no mention is made of the laminated clay, which I first observed in 1909, and the first record of boulder clay at Rothwell Haigh was made by Messrs. Jowett and Muff in 1904. Mr. W. Lower Carter, in his paper on the Glaciation of the Don and Dearne Valleys, mentions these deposits at Rothwell Haigh and Oulton, and in supporting his idea of the existence of a glacier-like in Calderdale, writes* :—

The northern edge of this lake (*i.e.*, Lake Calderdale) would creep up to and over the watershed of the Calder and Aire at Lofthouse and Rothwell, would discharge its waters over the gap at Tingley into the Churwell valley and lapping round Middleton, would be bounded northward by the Airedale Glacier. This lake

* *Proc. Yorks. Geol. Soc.*, Vol. XV., Pt. III., p. 435.

would serve to explain the Rothwell and Oulton Gravels which cap the watershed between the Aire and Calder from the 175 ft. to the 250 ft. contour. I regard these detrital deposits, often well bedded and associated with fine tenacious clays, as part of the lateral moraine of the Airedale Glacier rearranged in the lake which washed the side of the glacier.

Now, whilst I am disposed to agree with the statement that a lake existed here—as is indeed evidenced by the presence of the laminated clay—a little more explanation is needful than that given in the latter part of the quotation. Mere rearrangement of the material will not suffice to give us the succession found at Rothwell Haigh, where we have coarse gravel at the base, succeeded by sands becoming finer towards the top, and these surmounted by laminated clay and capped by boulder clay.

This series of beds represents a succession of conditions in this area such as might result from a glacier gradually approaching and creeping up the spur between the Aire and the Calder.

There were two glaciers which have to be considered in this area : (1) the ice coming down Airedale ; (2) the Vale of York ice.

Messrs. Jowett and Muff assumed that the Rothwell gravels were, in fact, the morainic product of the Airedale glacier, but there is certain evidence on this point which was not in their hands. Among the erratics of the boulder clay, I have mentioned Carboniferous limestone. Professor Kendall has pointed out that some of this limestone is of a type only to be matched by Carboniferous limestone to be found in situ about Richmond, and therefore beside the track of the Vale of York ice. Secondly, I have found in the gravel-pit pebbles which certainly have a wind-polished and pitted surface, and which seem to have belonged to the Trias of the Vale of York. I have not actually found these in situ in the boulder clay, but I can conceive no other explanation of their presence than that they were washed out of the clay. Thirdly, in the laminated clay are found boulders of Magnesian limestone. There is no Magnesian limestone on the route of the Airedale glacier. But the escarpment of the Magnesian limestone tract lies a few miles to the east of Rothwell. We may imagine these boulders then to have been rafted by bergs of ice from the advancing glacier and thrown down here.

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These facts convince me that the glacier in question was the Vale of York ice. Now, if this ice-front reached the spur between the Aire and Calder it must have obstructed whatever drainage of water accompanied the glacier in Airedale. At the earliest stage these Airedale waters would throw down their coarsest detritus as soon as they entered Lake Humber—which they would do just at this spot at Rothwell. But as the ice-front became higher and higher on the Aire-Calder spur, the Aire waters would be obstructed and the lower part of the Aire valley formed into a lake. The coarser detritus would be thrown down by the waters immediately they reached this lake, and, though it cannot be demonstrated with certainty, it may very well be that the deposit at Newlay, which is of exactly the same type as that at Rothwell, but at a height of about 200-250 ft., belongs to this stage. But as the confluence of the Aire waters with the Airedale lake advanced farther and farther away up the valley, the sediments reaching Rothwell would become finer and finer, until at length the ice-front itself covered the spot and brought the boulder clay.

RELATIVE AGE OF THE DEPOSITS AT ROTHWELL HAIGH
AND WOODLESFORD.

After what has been said above it need hardly be stated that a great interval of time must be represented between the period when the Rothwell gravels and clays were formed and that at which those at Woodlesford were deposited. The first was an early phase and the latter a somewhat late phase of the Glacial period. Indeed there is every evidence that as the glaciers retreated up the Pennine Valleys the great rush of melt waters would scour off the material laid down in deltas and as moraines upon the slopes of the valleys and spurs of the hills to redistribute it in the low ground, and especially to carry the fine material forward into Lake Humber, where it now forms the warp of the Vale of York.

EXAMINATION OF VARIOUS LAMINATED CLAYS.

With a view to throwing a little more light upon these widely spread clays I have examined a number from various parts of Yorkshire and Lancashire and, by the kindness of Prof. Leverett, from North America also.

I find that they are all of the same general character, being composed of light and dark layers. The light layers invariably yield an

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effervescence when treated with hydrochloric acid. They vary greatly in the number of laminæ to the inch, this being a function of their fineness.

Clays from various localities were taken and, after being dried at 100 deg. C. and finely powdered, were treated with cold dilute hydrochloric acid, when the following results were obtained :—

				<i>Percentage</i>
				<i>Insol. in HCl.</i>
Woodlesford	..	..	..	89·5
Rothwell Haigh	..	..	..	87·6
Victoria Cave	..	..	..	86·5
Danby (Cleveland)	..	..	..	83·4
Robin Hood's Bay	..	..	..	82·2
Brickfield, south east of York	..	..	..	72·0

A sample of lacustrine clay of glacial origin from Wisconsin, kindly forwarded to me by Prof. Leverett, gave 69·24 % insoluble in dilute hydrochloric acid.

The presence of irregular masses of carbonate of lime, and also of rhombohedral crystals of calcite has already been mentioned. So that it would seem that calcium carbonate (if all the soluble portion be reckoned as such) is an important constituent of all these clays. It is probable that the waters of the lakes contained a large percentage of calcium carbonate in solution—for it need hardly be pointed out that limestone forms much of the area from which the ice came, and also that calcium carbonate is more soluble in cold water than in warm. It is probable also that much of this calcium carbonate in the clays was originally secreted from the lake waters by algæ, of which no traces remain.

The finding of the laminated clay in the washpools at Rothwell Haigh and Newlay suggested the experiment of washing the sands from these deposits in the laboratory and allowing the fine material to settle. It was found that the resulting fine material gave a deposit consisting of a lower lighter and an upper darker layer, for every separate wash. Working with boulder clay from Rothwell Haigh it was found that it yielded all the material of the sands and gravels as well as the laminated clay. The heavy minerals were also the same though monazite was not found in such abundance as in the sands.

Evidently then, the Vale of York ice, which I have shown probably contributed the boulder clay, must have incorporated a large amount of material from the Millstone Grit, and the lesser quantity of monazite is quite in agreement with the fact that the Rough Rock was not so important a contributor to the burden borne along by this Vale of York ice, for the Rough Rock does not occur to the north, and it is the bed from which the greatest quantity of monazite has been obtained in my work upon the heavy minerals of the Millstone Grit.

Here, then, is a direct connection between the three types of deposit which may be helpful in elucidating some of the problems of the distribution of such deposits over such an area as the Vale of York. For instance, if quantitative work along such lines were carried out for a number of boulder clays and morainic material, and the thickness and area of the laminated clay over the Vale of York ascertained, it seems to me it would be possible to obtain the volume of the original material which must have been redistributed in order to yield it. A microscopical examination of the upper laminated clay of Woodlesford shows that it consists very largely of rock flour, being, in fact, a very finely divided quartz mud, and it would thus seem to be due to the grinding of fresh rock in Glacial times rather than to the old soils, residual earths and clayey material resulting from subaerial decay of the rock in pre-Glacial times. In the lower laminated clay at Woodlesford there is not so much rock flour and more clayey material, and doubtless differences of this kind would be found in whatever clays were examined, resulting from a sorting of the finer clay particles from the rock flour the further the area of deposition may be from the source of supply.