TRANSACTIONS

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GEOLOGICAL SOCIETY OF GLASGOW.

No. X.—THE STRATIGRAPHY OF THE ARDEN BASIN. By R. G. CARRUTHERS, H.M. Geol. Survey, and E. M. ANDERSON, M.A., B.Sc., H.M. Geol. Survey.*

[Read 14th February, 1907.]

By the term Arden basin we mean the elongated synclinal area, whose axis extends in an easterly or east-south-easterly direction from Barrhead as far as the White Cart. It is bounded on the south by the large upthrow fault, which brings in volcanic rocks of earlier Carboniferous date. On the other side its limits are not so clearly defined. To the north-east the inward or southerly dip extends, in spite of minor faulting, as far as the great fault, which lets down the Coal Measures at Strathbungo. Round the margins of this basin are areas of the underlying Coal-bearing group of the Carboniferous Limestone series, known as the Edge or Possil Coals, but all the central part is occupied by strata of the Upper Limestone group. These include strata ranging from the Cowglen or Index Limestone, which forms the base of the group, to some distance above the Arden Limestone. The strata above the latter horizon are shown on the old Survey map (sheet 30, 1-inch) as belonging to the Millstone Grit. But as a higher seam, namely, the Castlecary Limestone, is now adopted as the lower limit of the Millstone Grit, these strata are now included in the Upper Limestone series.

* Communicated by permission of the Director of the Geological Survey of Great Britain.

Before beginning the stratigraphical part of our paper reference may be made to the work of previous investigators. In the "Statistical Account of Scotland," vol. 7, published in 1845, under the heading of the parish of Eastwood, reference is made to the Arden and Cowglen Limestones, and it is recognised that they are separate seams. Nothing, however, is said about the Orchard Limestone, though the Giffnock Sandstone was already worked in two quarries. The eastern part of the ground which is the subject of our description was surveyed in 1868 by Professor (then Mr.) E. Hull and by Professor (then Mr.) James Geikie, at that time attached to the Survey. The Orchard Limestone was now being worked, and it was supposed that there were three beds of limestone in the Upper Limestone group—the Cowglen, Orchard, and Arden Limestones—in ascending order, the position of the Giffnock Sandstone being between the first and second. In February, 1869, a paper "On the Carboniferous Sections of the Lavern Valley, Renfrewshire,"* was read to this Society by Mr. Hugh M'Phail. In this paper he shows the important part played by the thick pebbly sandstone overlying the Index or Cowglen Limestone in the stratigraphy of the district. He identifies the limestone found in the reservoir south of the Waukmill Glen, rightly, as we think, with the Cowglen, and he records the presence of the Lyoncross Limestone in an intermediate position between it and the Arden horizon. He also correctly interprets the section in the Nitshill railway cutting, identifying the limestone there with the Lyoncross, and points out the necessity of supposing that there must be a large strike fault running along the north-western part of the basin. According to our present view, however, he fell into one mistake. Knowing only of one intermediate limestone between the Cowglen and the Arden horizons in the Waukmill Glen section, and of one limestone between the same two horizons near Giffnock, he naturally supposed that the two were the same. He thus correlated the Lyoncross with the Orchard Limestone, while the limestone lying beneath the Giffnock Sandstone he regarded, in common with the Geological Survey, as being the Cowglen. The western part of the district under consideration was surveyed by the officers of the Survey in 1870.

* *Glas. Geol. Soc. Trans.*, vol. iii., p. 234.

They mapped the limestone in the reservoir as the Cowglen, but they avoided expressing any opinion as to the correlation of the Lyoncross. The 6-inch Survey maps, which include the Arden basin, were published between 1869 and 1875; the 1-inch sheet to the south (No. 22) was published in 1870; the 1-inch sheet which includes the northern part of the basin (No. 30) was not published till 1878.

In December, 1881, the late Captain Stewart of Williamwood read his classical paper to this Society, entitled "Notes on the Limestones in the Parishes of Cathcart and Eastwood, Renfrewshire."* In this he clearly showed, from bores sunk at Orchard and beside the Hole Burn S.E. of Pollokshaws, as well as at other places, that the limestone immediately underlying the Giffnock Sandstone was not, as had been supposed, the Cowglen Limestone, but a separate band lying about 40 fathoms above that horizon. He thus determined the presence of four limestones in the Upper Limestone series of this district, namely, the Cowglen, Hole Burn, Orchard, and Arden, the Giffnock Sandstone lying immediately above the Hole Burn Limestone. Captain Stewart also showed that both the Hole Burn and Orchard Limestones are present in the southern part of the basin. He believed that the latter occurred in some places in two bands, one of which it was which was exposed in the Rouken Glen just below Thornliebank House. His paper was accompanied by a geological map, which added a great deal to the previous knowledge of the district, and to which further reference will be made in the sequel.

In December, 1889, the late Mr. Murdoch contributed a few notes on the journal of a bore put down for water at Thornliebank, which was published, together with Mr. Murdoch's interpretation, in the *Transactions* of this Society.† In a paper recently published‡ Mr. Macnair puts forward the view that there are three instead of two limestone horizons between the Cowglen and the Arden. The extra one, it is unnecessary to remind the Society, is named by him the Rouken Glen Lime-

* *Glas. Geol. Soc. Trans.*, vol. vii., p. 158.

† "Journal of a Bore put down for Water at Thornliebank, Renfrewshire. With notes on the strata."—*Glas. Geol. Soc. Trans.*, vol. ix., p. 207.

‡ "The Geology of the Rouken Glen and its Neighbourhood."—*Glas. Geol. Soc. Trans.*, vol. xii., p. 362.

stone, which he supposes to come above the Orchard, and to be the one which occurs in the Rouken Glen, and also at Thornliebank. The result of our joint revision of the area has been, in our opinion, to confirm the view previously adopted by Captain Stewart, and also to establish the identity of the Hole Burn Limestone with the Lyoncross.

In an investigation of this nature it is desirable to use as a datum line some definite zone whose course can be accurately traced throughout the district. In the present case a satisfactory line is afforded by the Cowglen or Index Limestone. Occurring, as it does, just above the group of the Possil Coals, this limestone has been proved at several points in the district through mining operations, while it is likewise exposed in many natural and artificial sections, where, as will be seen later, the peculiar lithological characters of the accompanying strata allow of a ready identification of this horizon in the field. We propose to follow the outcrop of this limestone round the basin, using the data so obtained to fix the position of the various members of the Upper Limestone group.

We shall first describe the succession from the Cowglen Limestone up to the Orchard, as met with round Giffnock and Orchard. In some respects this district presents what we may take as the type section for the area with which we are dealing. The lower part of the succession is proved by the journal of a bore which was put down close to the Giffnock Colliery (see A, Plate VII.). The same strata were afterwards passed through in deepening the shaft.

The Cowglen Limestone in this bore has a thickness of 5 feet 10 inches, and has 4 inches of coal below it, and separated from it by only 2 inches of limy blaes. It is in one post, and above it is a thickness of 32 feet of blaes with ironstone nodules. Above the blaes comes a post of sandstone, which is succeeded by 2 feet 2 inches of "hard, limy fakes" at a distance of 13 fathoms above the Cowglen. This is the equivalent of the local limestone seam, which is described at about the same distance above the Cowglen Limestone in several of Captain Stewart's bores. Then comes more sandstone with a little blaes, and no fewer than four thin seams of coal. Above the highest of these comes an uninterrupted post of 13 fathoms of sandstone; parts of this are described as coarse, and have

EXPLANATION.

been picked out in the vertical section. Just above the sandstone is a thin coal. A short distance further up is the coal which was formerly worked at Giffnock Colliery. It is 3 feet thick, but here at least it is poor in quality. Two fathoms above it comes the Hole Burn Limestone, and we may, in the meantime, refer to the coal seam as the Hole Burn Coal. The limestone itself is in two leaves, 3 feet 3 inches and 1 foot 4 inches in thickness, and separated by 1 foot 6 inches of dark blaes. Here the section as given in the bore journal ceases, but in an old shallow shaft, just a little to the north of the present Giffnock Colliery buildings, the upper band of limestone is seen to be separated by 4 feet of blaes from the base of the Giffnock Sandstone.

The points we wish to emphasise in the section so far considered are—

(1) The Cowglen Limestone is in a single post, and has no coal below it worth speaking of. Above it are more than 5 fathoms of blaes.

(2) From above this blaes to not far below the succeeding Hole Burn Limestone comes a series in which sandstone plays by far the largest part. Parts of this sandstone are of a coarse and gritty character.

(3) Underlying the Hole Burn Limestone, and about 2 fathoms below it at Giffnock, is a coal of moderate thickness. The limestone itself is in two parts, close together, and separated from the overlying sandstone by only about 4 feet of blaes.

As we proceed, each one of these points will be seen to be of importance for purposes of correlation.

The remainder of the section in this district is given by the Orchard bore (No. 2 in Captain Stewart's paper, before referred to),* together with the numerous quarries which have been opened in the Giffnock Sandstone and the former workings in the Orchard Cement.

Reckoned up to the position of the Moor Rock Coal, the sandstone quarried at Giffnock has sometimes a thickness of 60 feet. The term Giffnock Sandstone, however, is sometimes restricted to the lower part of this thickness, which is otherwise known

* Captain Stewart presented the complete journals of all the bores referred to in his paper to the library of the Society.

as the Liver Rock. For the purposes of this paper we shall use the term Giffnock Sandstone in a broad sense to include all the sandstone between the Hole Burn Limestone and the Orchard Cement, whether above or below the position of the Moor Rock Coal. The coal referred to is best exposed in the New Braidbar Quarry, where it is 14 inches in thickness. It is shown to be inconstant by the fact that neither in Williamwood Quarry to the south-east nor in the nearest quarries to the north-west, in which its position is exposed, is there any sign of it. It even dies out to the east in New Braidbar Quarry itself. Neither is there any mention of it in the Orchard bore. This bore shows the total thickness from the base of the Orchard Cement to the blaes above the Hole Burn Limestone to be about 27 fathoms; this distance is almost entirely occupied by sandstone, but there is a 7-inch coal about 2 fathoms below the cement. There is also a thin coal just immediately below the cement, separated from it by only an inch or two of blaes, and formerly mined along with it. This is evidently a different seam from the one met with in the bore, and we thus see that three horizons of thin coals occur in the interval between the Hole Burn Limestone and the Orchard Cement. We shall find this fact also useful for purposes of correlation.

Coming now to the Orchard Cement Limestone, its thickness at Orchard itself is 2 feet, and 15 feet of blaes above it were exposed in the old workings. This, however, does not represent the total thickness of the Orchard blaes, which is best seen in Bore No. 1A of Captain Stewart, which was put down to prove the limestone about a mile S.E. of Orchard. In this bore there is a thickness of 7 fathoms of "dark fakes" above the limestone, and in this case the term evidently refers to blaes. Above these "fakes" comes a "kingle," 1 foot 1 inch, and this we take to be an upper band of limestone. We shall find further evidence as we proceed of the presence of this upper band a few fathoms above the band of limestone which was first recognised, and we shall distinguish the two in future by the terms Lower and Upper Orchard Limestone. The existence of the Upper Orchard, as before remarked, was known to Captain Stewart.

Above the Upper Orchard Limestone the section, as definitely known in this district, ceases. In our table of vertical sections (Plate VII.) we have indicated what we suppose is the completion of the section up to the Arden Limestone. We do not think that any further beds of limestone occur in this interval. The Upper Orchard is, we believe, succeeded by a further thickness of blaes, and above this is mostly sandstone till we come to the one or two thin coals which underlie the Arden Limestone. The thickness from the Upper Orchard to the Arden we take in round numbers to be about 25 fathoms, and the total thickness from the Cowglen Limestone up to the Arden is about 90 fathoms. Our reasons for these conclusions will become apparent as we proceed. The figures here given are in agreement with those indicated in the tabular comparison of bores drawn up by Captain Stewart.

At the old mining district of Nitshill, on the north side of the basin, a very good section of the beds overlying the Cowglen Limestone is seen in the railway cutting east of the station (B, Plate VII.). The strata dip uniformly south-east at angles of from 15 degs. to 25 degs., and, with the exception of a large fault terminating the section on the east, present an unbroken succession. The fault referred to, as noticed by Mr. M'Phail, was at one time well seen in the cutting, but is now concealed. It runs in a south-westerly direction to Barrhead, having a downthrow to the south-east of from 20 to 60 fathoms.

The succession, as measured in the cutting, is in descending order—

These Sandstones are all fine grained.	{	White and grey sandstones, with thick blaes partings, 21 ft.
		Broken yellow and white flaggy sandstone, 17 ft. ; blaes parting, 6 ins.
		Yellow and white sandstone, in good beds, 27 ft.
		Dark blue shale, with small ironstone nodules, 0-3 ft.
Hole Burn Seams.	{	Cement lime-stone, { cement, 1 ft. 4 ins., blaes parting, 0-9 in., } 3 ft. 6 ins.
		Flaggy yellow and white sandstone, 21 ft. ; coal, 1 ft. 4 ins. to 2 ft.
		Massive sandstone, coarse and gritty at base, 25 ft.
		Massive soft grit, 31 ft.
		Fake and blaes (with a band of sandstone and fireclay, 7 ft. 6 ins.), about 25 ft.
		Massive grit, with pebbly bands, 40 ft. seen.

The cement has a bright ochreous weathering, rendering it a conspicuous object in the cutting. It is grey on a fresh surface, and contains small brachiopods and crinoid stems, though not in any great abundance. No fossils, however, were observed in the overlying blaes.

The coal was worked by Mr. Kirkwood, of Darnley, down to the large S.W. fault; the old workings, with some of the old wooden props for the roof, can be seen on the south wall of the cutting.

The massive grits in the lower part of the section are coarse, and full of strings of white quartz pebbles. They are slightly ferruginous and soft, disintegrating readily on exposure. We hope to show that these grits preserve their character throughout the basin.

The Cowglen Limestone, though not seen in the cutting, must immediately underlie the base of this coarse grit; for a few yards to the north of the westerly railway bridge an old pit was sunk 15 fathoms to the Boghouse Coal—a seam lying from 18 to 20 fathoms below that limestone. As the mining evidence in this locality shows the absence of any fault which would affect the strata in the cutting, the crop of the limestone may be laid down on the map with some accuracy.

Leaving the cutting and proceeding in a south-westerly direction, we find within half a mile a good escarpment of the pebbly grit west of Wardhill Farm. Mr. M'Phail observes that at this spot on the ridge a pit was sunk through the grit reaching the Cowglen Limestone, here 10 feet thick, at a depth of 14 fathoms.

A little further south, just beyond Parkhouse and near the main road to Barrhead, a disused sandstone quarry is seen in the upper bands of the pebbly grit. Overlying the sandstone occurs a coal about 1 foot 6 inches thick, which was worked for a short distance inwards, till cut off by a large downthrow fault (a continuation of the one in the Nitshill railway cutting). According to Mr. M'Phail, the coal was also found in a well at Parkhouse, close by.

In the quarry a bore was put down from the coal outcrop (C, Plate VII.), and, after passing through 30 fathoms of sandstone, went through the Cowglen Limestone, and proceeded well down into the Possil Coal series beneath.

Comparing the sections, it is seen that the Parkhouse Coal is the same as that worked in the Nitshill cutting, 21 feet below the cement, *i.e.*, it is the Hole Burn seam. At Barrhead a continuous escarpment of the pebbly grit is seen, in which several old quarries have been opened to the north-east of the town. As noted by Mr. McPhail, most of the old part of Barrhead is built on the continuation of this ridge, while the Cowglen Limestone underlying the grit was struck in the foundations of the Arthurlie Biscuit Factory, in the centre of the town.

South and south-east of Barrhead a number of most interesting sections are seen. In the goods yards, just west of Upper Arthurlie Bleach Works, there is an exposure of the pebbly grit, dipping S.E., while in the Kirkton Burn, to the south, the grit is again seen lying with a sharp junction line on a series of fine-grained, flaggy sandstones, both dipping to the N.W., the strata thus forming a small basin whose extent has been fully proved by the workings of the Barrhead Main Coal. This seam, formed by the coalescence of two smaller ones (some 7 feet apart at Nitshill), lies about 20 fathoms below the Cowglen Limestone, and has been extensively wrought round Barrhead in the past. The crop workings are still visible in the Kirkton Burn. West of the burn is a deep cutting in a new branch of the Caledonian Railway connecting Barrhead with the Ardrossan line. The section is an important one, as it gives a clear idea of the strata associated with the Cowglen Limestone (see Fig. 1). At the west end of the cutting an anticlinal fold is seen—the complement of the syncline just described. The lowest beds are white sandstones, with numerous grey fireclay partings, with a bed full of irregular ironstone nodules on the top. Overlying this is a streak of cannel coal with fish remains, followed by blaes, with partings of hard, ferruginous sandstone. This, again, is overlain by sandstone with two thin coals, on which rests a succession of massive, fine-grained, yellow and white sandstones 33 feet thick, with much ferruginous staining on the outside. Above this sandstone is seen the great grit, the line of junction indicating unconformability or local erosion. Sometimes the grit rests directly on the fine-grained sandstones, but usually

Fig. 1.

there is a parting of blue blaes with ironstone nodules, while at two places close to a fault with a downthrow to the east, crossing the cutting at the small plantation, it lies on a lenticular limestone band. This limestone—a thickness of 2 feet is visible—is ochreous, very hard, somewhat dolomitic, and is almost destitute of fossils. Pebbles both of the limestone and the ironstone nodules of the associated blaes occur at the base of the grit. That this lenticular limestone is the Cowglen is shown not only by its occurrence at the base of the grit, as at Nitshill, Wardlaw, Parkhouse, and the biscuit factory, but by its distance above the Barrhead Main Coal, which can be readily calculated, since the coal has been worked all through the immediate district, and its outcrop is seen in the Kirkton Burn close by. The fault just mentioned as crossing the cutting has been proved at several points in the workings to have a downthrow of 6 fathoms.

From this evidence we may reasonably infer that the erosive junction between the great grit and the underlying fine-grained, flaggy sandstones, as seen in the Kirkton Burn, is on the horizon of the Cowglen Limestone; in fact, a note on the old Survey 6-inch map records "limestone 2 feet" in the burn at this spot. Part of the section is now obscured, and the limestone is no longer visible here. The erosive junction is again seen in a streamlet joining the Kirkton Burn just south of the Upper Arthurlie Bleach Works.

The great grit occupies the remainder of the railway cutting, which furnishes an excellent section of this important zone.

With the exception of a short gap, the section is continued eastwards into Springfield Glen (see vertical section, D, Plate VII.). At the head of the glen, south of the new railway bridge, the pebbly grit overlying the Cowglen horizon is well shown in a cliff section. It becomes finer-grained in its upper portion, as at Nitshill, and is overlain north of the bridge by a workable coal. Three old "ingoing eyes" to this coal are seen on the west side of the glen. Above the coal workings 16 feet of faky sandstones supervene, overlain by a band of cement limestone, divided into two seams by a thin parting of blaes, the lower bed being 2 feet 5 inches thick and the upper

one 9 inches. Immediately above the cement come a series of fine-grained faky sandstones, with a coal streak about 40 feet above the cement. The identity of this glen section with that in the Nitshill railway cutting is obvious. The junction of the fine-grained, faky sandstones with the underlying cement is marked by a thin pebbly band about an inch thick, and there would appear to have been some local erosion here also, as one or two deeply-weathered pebbles of the cement were found in the band.

The section ends immediately beyond the coal streak 40 feet above the cement, but a short distance further down the stream, in a bore for water at the South Arthurlie Print Works, two thin bands of cement were found separated by 27 feet of blaes. The section, which is shown in the upper part of D, reads as follows:—

	Feet.	Inches.
Depth of well, - - - - -	13	0
Cement <i>limestone</i> , - - - - -	1	11
Blaes, limy and with lime balls in upper part, -	27	0
Cement <i>limestone</i> , - - - - -	2	3
Dark limy blaes, - - - - -	2	5
Coal, - - - - -	1	7
Hard sandstone, - - - - -	3	0
Fakes and a little blaes, - - - - -	12	2
Total, - - - - -	64	8

Unless some unknown fault exists, these cements lie about 120 feet above the one seen further up the glen, which has been correlated with that in the Nitshill cutting, and they have been shown in that position in the vertical section D. Eastwards along the railway another cutting is soon reached half a mile west of Lyoncross, which furnishes evidence of great interest. This locality is near the great E. and W. boundary fault, which lets down the Lower Carboniferous volcanic rocks against the Carboniferous Limestone series. Indeed, the position of the fault is indicated in the cutting (see Fig. 2). All the strata dip N. or N.W. The pebbly grit, which is the highest bed exposed, occurs at the west end of the cutting. It is worthy of note that the grit is here pierced by a remarkable whinstone dyke full of foreign boulders, such as limestone, sandstone, blaes, and various types of igneous rocks, apparently derived from a crush breccia in the boundary fault. At

Fig. 2

several other places near Barrhead small whinstone dykes may be noticed invading the sediments in the neighbourhood of the great fault.

Under the grit and on both sides of the railway bridge is seen a very hard, ochreous, grey weathering limestone, with very few fossils. It is very lenticular, and is usually overlaid by a thickness of 2 or 3 feet of blue blaes, with ironstone nodules. The limestone rests on a series of hard, fine-grained, flaggy, white sandstones, with much ferruginous staining. The junction of the pebbly grit with the underlying rocks is highly irregular. On the south side of the railway bridge it rests in turn on the limestone, the blaes with ironstone balls, and on the fine-grained sandstones below; pebbles of ironstone and limestone are found at the base of the grit. It will be seen that the section here is identical with that exposed in the deep cutting south of Barrhead; there can be no doubt that we are here dealing with another exposure of the Cowglen Limestone and the very characteristic strata associated with it.

The underlying flaggy sandstones show signs of great disturbance, and are brought against a limestone, weathering a pale blue colour, of a very different character from those already described. The band is 13 feet thick, the upper half having several partings of limy blaes, while at the base is a post of good, hard limestone 4 feet 8 inches thick, divided by half an inch of blaes. All the limestone is fossiliferous, small brachiopods being especially abundant, there being also small Zaphrentid corals, *Lithostrotion junceum*, and other forms, besides an abundance of crinoid stems. Both lithologically and palæontologically this rock bears a strong resemblance to the Thorntonhall Limestone, so well seen some 3 miles to the east. A little digging in the embankment showed that, like that limestone, the one in the cutting rests on ashy blaes, quickly followed by red, yellow, and green tuffs, which in turn are seen to rest on lavas further along the cutting. In fact, the boundary fault runs between the two limestones seen in the cutting. As calculated from other data in the district, the throw of this fault must be over 250 fathoms at this spot.

The Cowglen Limestone is again exposed in a small quarry

200 yards east of Auchinback, and just north of the filter bed. The limestone here is somewhat crystalline in its upper part. In the quarry it is overlain by the pebbly grit, while under the limestone come the fine-grained, flaggy sandstones exactly as in previous sections.

Before describing other sections we may now summarise the evidence advanced in the foregoing pages. It may be regarded as established beyond doubt—

(1) That the Cowglen Limestone of the Barrhead district is underlain by 30-40 feet of fine-grained, flaggy sandstones.

(2) That the limestone itself is lenticular in character along the south side of the basin, owing to erosion and irregular deposition.

(3) That it is overlaid by a massive pebbly grit up to 30 fathoms thick, which is succeeded by a coal seam averaging 1 foot 6 inches in thickness (the Hole Burn seam).

(4) That about 16 feet above the coal comes a cement limestone averaging 3 feet 6 inches in thickness, having a thin parting of blaes in the middle.

(5) That the succeeding beds are fine-grained, flaggy sandstones, and that a thick mass of blaes with two thin cement bands occurs, probably, but not certainly, about 16 fathoms above the thick cement.

About 100 yards N.E. of the filter bed quarry is a small ravine, in which a coal occurs in flaggy sandstones, having a cement limestone 14 feet above it. Both coal and cement were at one time worked, the coal being known as the Lyoncross seam, from the farm of that name close by. It was 1 foot 4 inches in thickness, and of good quality; according to Mr. M'Phail, the workings were continuous with those in the Wauk-mill Glen, half a mile to the east. We hope to show, from the evidence to be brought forward in the sequel, that the Lyoncross seams of coal and cement are identical with those seen in the Nitshill railway cutting at Parkhouse and at Springfield Glen. From the mapping, it is evident that a large fault must intervene between the Lyoncross seam in the small dingle and the Cowglen Limestone exposed in the filter bed quarry. It is interesting to note that this fault has been proved in an open cast working for cement at Little Auchinback,

half a mile to the N.W., to which reference will presently be made.

Not far to the east the well-known section in the Waukmill Glen occurs. We hope to show that, with the exception of two short gaps, there is here displayed a complete section of the Upper Limestone group, from the Cowglen up to the Arden Limestone, inclusive (see vertical section, F, Plate VII.). The dip of the strata in the upper part of the glen is steadily to the N., veering round to N.W. Consequently, the lowest bed crops out at the head of the glen and in the reservoir beyond.

Mr. M'Phail noticed that the Cowglen Limestone cropped out in the reservoir, where it was overlaid by the "thick-bedded sandstones." During the original Survey of this area Professor Hall, in noticing this fact, gives a section in his notebook, showing that, under the water tower in the reservoir, the limestone—here only 2 feet 6 inches thick—was overlain by a foot or so of dark blaes, succeeded by the massive pebbly grit. This particular section is now under water, but a similar one is seen in the quarry at the N.E. end of the reservoir, where nearly 40 feet of the fine-grained, flaggy sandstones under the limestone are seen. The limestone itself is 6 feet thick, the upper part deeply weathered to an ochreous clay, though the lower part, as is usual in these limestones, is of better quality and but slightly weathered. The difference in thickness of the limestone, as observed at the E. and W. ends of the reservoir, is, of course, in accordance with the lenticular nature of the Cowglen band, along the south crop, to which reference has already been made. On the west side of the quarry a small fault, well seen when the water is low, brings down the pebbly grit against the limestone.

Returning to the west end of the reservoir, and following the course of the Brock Burn as it flows down into the Waukmill Glen, the first section noticed is a fine exposure of the great grit, the beds dipping at an angle of 16 degs. to the north. The upper portions are, as usual, fine-grained and with some faky partings. Above are seen the workings of the Lyoncross Coal, and 14 feet higher up comes the Lyoncross Cement. The latter, like the limestone occupying a similar position at Nits-hill and Springfield, which at Nitshill has been correlated with

the Hole Burn Limestone, is divided into two beds by a thin parting of blaes. The lower post, 2 feet 4 inches thick, is the only one used for commercial purposes, the upper post, 1 foot thick, being of poor quality. Above the cement, as is well known to many members of the Society, comes a thick mass of blaes, containing bands of marine fossils in an excellent state of preservation. This feature, it will be noticed, is not seen in the sections at Springfield and Nitshill, although a comparison of these sections must, we think, leave no doubt as to their identity.

Above the Lyoncross Cement is a succession of 90 feet of strata, chiefly consisting, with the exception of the fossiliferous blaes just mentioned, of flaggy sandstones, having two coal streaks about equal distances apart. The best post of sandstone is at the top, and on it lies a band of cement limestone 1 foot in thickness; a short working was made in this cement, but the seam proved too thin, though of better quality than the Lyoncross band. Overlying it are seen 10 feet of limy blaes, in which, as far as we know, there are no fossils. Immediately beyond this point, just where the fence crosses the glen, a second cement band, 9 inches to 1 foot in thickness, was found by us on clearing away the surface soil. It lies about 16 feet above the lower band. It will be seen that the position of this thick mass of blaes, with the two thin cement bands, agrees well with that found in the boring at the South Arthurlie Print Works, and which was provisionally ascribed to a horizon about 100 feet above the Lyoncross Cement seen in Springfield Glen.

After a short gap the section is continued further down the stream, the dip of the strata swinging round to the N.W. The first beds seen are dark fakes and blaes exposed just above the small bridge crossing the burn. Immediately beyond the footbridge these are truncated by a fault, whose throw may be calculated, from workings in the Arden Limestone at this spot, to be about 12 fathoms.

Beyond the fault appear the flaggy sandstones below the Arden Coal, followed by the coal and a thin band of sandstone, succeeded by a mass of limy blaes passing up into the Arden Limestone. These strata, crossing the stream where it

bends to the N.W., are well known, and need no detailed description here.

The thick mass of shale containing two thin cement bands 16 feet apart may be calculated, from the field evidence, to lie about 25 fathoms below the Arden Limestone, unless a fault crosses the stream through the short gap in the section just above the bridge. There is no evidence for such a fault in the extensive quarries in the Arden Limestone in this district, nor is one recorded from the workings of the Lyoncross Coal to the west. On the other hand, confirmatory evidence of the position of these two cement bands relatively to the Arden Limestone and the Lyoncross Cement may be obtained from a bore put down half a mile to the N.W., about a quarter of a mile S.E. of Parkhouse (Salterland No. 2 Bore, see vertical section E, Plate VII.). This bore starts 25 fathoms above the Arden Limestone. After passing through that seam ($12\frac{1}{2}$ feet thick) and the coal beneath, it went through a series of fakes and sandstones, and, at a depth of 21 fathoms below the Arden, entered a mass of limy blaes $11\frac{1}{2}$ fathoms thick, having two thin cement bands 10 inches and 6 inches thick—one in the middle and the other at the base of the blaes. Further down the bore passed through another series of fakes and sandstones with two thin coals, as at Waukmill Glen, underlain by another cement 4 feet 7 inches thick, with a parting of blaes, and terminating just beyond a coal 24 feet beneath. A comparison of this bore with the section in Waukmill Glen proves, in our opinion, the identity of the thick mass of blaes and two thin cement bands seen in the two sections. Further, the two thin coals below are similar to those seen in the Waukmill Glen above the Lyoncross Cement. An interesting point of difference between the sections is that below the lower coal streak a solid post of sandstone 32 feet thick was met with in the boring, while at the same position in the Waukmill Glen only blaes, with fakes and sandstone in the upper portion, are seen. Again, in the bore the cement, 4 feet 7 inches thick, agrees with the Lyoncross Cement, and the coal, 24 feet below the cement, occupies the position of the Lyoncross Coal. Although in the bore this coal was only recorded as 2 inches thick, it must be remembered that it was met with over 80 fathoms

down, a depth at which the thickness of a coal seam, always liable to be underestimated in a chisel boring, would be easily miscalculated.

Before leaving the Barrhead district, it may be as well to record some additional facts which throw light on the distribution of the various members of the Upper Limestone group in other parts of this district.

The Arden Limestone was worked by Mr. Macara a few years ago on the west side of the Free Church manse at Barrhead, in continuation of the Dovecothall workings mentioned by Mr. M'Phail. The limestone here was highly inclined to the S.E., and the workings were brought to an end by a downthrow fault, shifting the crop of the limestone further to the south. It was again found near the lodge at Arthurlie House, in a drain section which cut through the upper parts of the limestone and the overlying blaes. Lithologically, the stone was the same as that seen in the Darnley Quarries, and showed none of the ochreous weathering seen in the cements below this position.

A cement limestone of excellent quality was also worked by Mr. Macara south of Little Auchinback. The journal of shallow bores and other information in the vicinity show that this cement is in all probability the lower one of the two thin upper bands found in the No. 2 Salterland Bore, and seen in the trial workings in the Waukmill Glen. Mr. Brown, the manager of the works at Waukmill Glen, identified both the Little Auchinback stone and the small one in the Waukmill Glen as the Orchard Cement, largely owing to the resemblance in quality and appearance. The evidence which we have brought forward supports this conclusion.

The workings at Little Auchinback were brought to an end by a large downthrow fault running in a S.E. direction. A bore put down on the other side of the fault at this spot pierced the Arden Limestone at a depth of 10 fathoms. The fault has accordingly a throw of about 40 fathoms. Its further continuation has been noticed previously at Lyoncross, where it brings the Cowglen Limestone against the Lyoncross Coal—corresponding to a throw of 30 fathoms at this spot.

The Lyoncross Coal was worked many years ago S. of Barr-

head on both sides of the 6-fathom fault described as crossing the new cutting of the Kirkton Burn at the small plantation.

By tracing the massive pebbly grit with the underlying Cowglen Limestone and the overlying Hole Burn Coal and Limestone round the basin from Nitshill, we consider we have established the identity of the former with the limestone occurring in the reservoir, and of the latter seams with the Lyoncross Coal and Limestone. It follows as a natural consequence that the thick blaes with the two cement bands occurring higher up in the section correspond with the Orchard Blaes and Limestones, and this conclusion is borne out by the correspondence in many points of detail.

While agreeing with the previous correlation of these latter bands with those seen in the Rouken Glen, and to be described in the sequel, we cannot, in the face of such overwhelming evidence to the contrary, regard the Lyoncross seam as the Orchard, the great grit as the Giffnock Sandstone, and the reservoir limestone as the Hole Burn Limestone, as has previously been done. We consider that the Waukmill Glen section furnishes the key to the structure of the district. By comparing it with the Salterland No. 2 Bore section, we have obtained presumptive evidence of the thickness of strata intervening between the Orchard and Arden, and of the fact that no further bands of limestone occur within the interval.

We shall next compare the vertical section of the strata exposed in Waukmill Glen with those of the bores in the Arden Quarry (No. 7 of Captain Stewart) and of the bore at Thornliebank. With regard to the Arden bore not much need be said, as the section in it is practically the same as that in Salterland No. 2, and can be correlated with certainty. The coal which we take to be the Lyoncross seam, and which was poorly represented in the Salterland bore, is probably not reached. If we interpret the zone, entered "Mussels, 3 feet 6 inches," to mean a shelly limestone, as seems probable, then the limestone which we suppose to be the Lyoncross band retains its two divisions, as usual, close to each other, and surmounted by only a few feet of blaes. The Moor Rock Coal is absent, according to our interpretation, and a sandstone and thin coal have come in between the two bands of the Orchard Limestone, which, however, maintain their relative distance.

Of more importance is the correlation between the Waukmill Glen section and the Thornliebank bore (G, Plate VII.). The limestone occurring near the base of the section in the latter bore we interpret to be the Cowglen. It has been otherwise correlated with the Hole Burn Limestone, but, in the first place, it is thicker (7 feet 4 inches) than any known occurrence of the Hole Burn or Lyoncross bands. On the other hand, it is not so thick as the Cowglen has been recorded in at least one of the bores published by Captain Stewart (No. 14B). Further, the fact that the limestone is in one post, and the absence of anything to correspond with the Lyoncross Coal, both point to the correlation with the Cowglen as the more likely hypothesis. In the next place, the overlying 20 feet of dark fakes, which we are justified in regarding as blaes, is thicker than any known occurrence of the blaes above the Lyoncross Cement; but it is not thicker than the blaes above the Cowglen Limestone at Giffnock Colliery.

The great mass of sandstone which occurs in the Thornliebank bore between this limestone and the next one above it has been held to include the Giffnock Sandstone. It may equally well be the equivalent of the Barrhead Grit, which we have followed almost round the basin; this would involve a much slighter increase in the thickness of the strata than the other assumption. The coal seam (6 inches) occurring near the middle of the sandstone has been taken for the Moor Rock Coal, but it may be the same as any one of the four different seams occurring between the Cowglen and the Lyoncross positions at Giffnock Colliery. Higher up in the section a coaly blaes (5 inches) or a coaly fireclay (1 foot 4 inches), occurring a little below the succeeding limestone, may either of them represent the Lyoncross Coal. As for the overlying limestone itself, it agrees better in thickness with the Lyoncross seam than with the Lower Orchard, which in its thickest known development, apart from this bore itself, is only 2 feet 3 inches. If we suppose the two divisions of this limestone to correspond with the two bands of the Orchard, this partly disposes of the difficulty about thickness, but, on the other hand, we have to assume that 16 to 30 feet of strata are represented by no more than 1 foot 2 inches of limy fakes. If, on the other hand, we

take this band to represent only the Lower Orchard, then, apart from the difficulty about thickness, what has become of the upper band of limestone which has been found in the Waukmill Glen? In any case, the 7 feet of dark fakes or blaes above this limestone is too thin to represent the Orchard Blaes.

Just above this blaes band comes a thickness of 23 feet of sandstone, fakes, and ribs. When we bear in mind the readiness with which all sandstones thin out laterally, and pass into such assemblages of sandstone and fakes, it is natural to suppose that this zone represents the Giffnock Sandstone, restricting the term to the sandstone which underlies the Moor Rock Coal. A little higher up in the bore journal is a coaly fireclay (1 foot 2 inches), which is regarded by us as the equivalent of the Moor Rock Coal. Higher up we find more sandstone, representing the higher posts of sandstone near Giffnock, which is followed by the limestone bands accompanied by the great thickness of blaes. These we take to be the Lower and Upper Orchard seams, together with the Orchard Blaes. On comparing the journal of this bore with the Waukmill Glen section, we think it will be admitted that our interpretation presents least difficulty. In particular, if we suppose that the lowest limestone in the Thornliebank bore is the Lyoncross band, then the sandstone, &c., which separates it from the Orchard must thin out from 278 feet at Thornliebank to 100 feet only in the Waukmill Glen, and to 173 feet eastwards to Orchard. Our own hypothesis requires a thinning of from 173 to 123 feet for the same set of strata as between Orchard and Thornliebank. As it is proved that the strata in this interval thin out westwards between Orchard and the Waukmill Glen, it is natural that, at an intermediate point, like Thornliebank, they should have an intermediate thickness, and hence be thinner than at Orchard.

We have also drawn up in graphic form the journal of the Kennishead bore—No. 8 of Captain Stewart, with whose reading we agree (see I, Plate VII.). It is possible that the top band of the Orchard Cement is just "off," and that both the bands mentioned in the bore journal at about 11 fathoms are really on the horizon of the Lower Orchard. The interval between this and the Lyoncross Limestone has undergone a further

shrinkage to 72 feet, while there is nothing better in the bore journal to represent the Giffnock Sandstone than about 16 feet of sandstone plies. At the same time, the difficulties of reading the bore journal in any other way are even greater. For instance, if the limestone at 23 fathoms is the Orchard, then the Orchard Blaes is poorly represented, while the upper band of limestone has entirely disappeared.

We think that the simplest way to interpret the bore is to suppose that the Giffnock Sandstone is undergoing a thinning process in this direction, while the underlying and overlying beds, as a result, come closer together. This is often the case where thick sandstones die out between different coal seams, and it is well known that many sandstones are very inconstant, and may die out in a comparatively short distance. It may be added that we have a bore journal from a point considerably further north, at the old Lancefield Forge, not much south of the Clyde, in which the Giffnock Sandstone is poorly represented. The Barrhead Sandstone is much more persistent, and is present both in this bore and at other localities afterwards to be described.

Returning to the neighbourhood of the Waukmill Glen and proceeding eastwards, an exposure of the pebbly sandstone is seen at Hillfield Quarry by the roadside 1 mile E. of the glen. A bore put down in the field on the N.W. side of the road opposite the quarry proved 2 feet 8 inches of limestone at a depth of 2 fathoms, while 13 feet below the limestone a coal 1 foot thick and coaly blaes 2 feet 5 inches was found. From the dip in the quarry these beds must immediately overlie the grit, and, from the general section and characteristics of these strata, there can be no doubt that we are here dealing with another outcrop of the Lyoncross seams. The blaes above the limestone in this bore was only 2 feet 6 inches thick, unlike that seen in Waukmill Glen. Further east, what corresponds to the pebbly sandstone is seen about 1500 feet south of Thornliebank House, and just north of the railway, in an old quarry marked by a line of wood. Here the pebbly character is not so marked. About 200 feet north from the quarry other exposures of sandstone occur, the latter being regarded by us as occupying the position of the Giffnock Sand-

stone. Our reasons for this conclusion are as follows:—(1) The gap, taking account of the dip, is wide enough to admit both the Lyoncross Coal and Limestone; (2) we have been informed by Messrs. Baird & Stevenson that a "blue whin" was found in this position. It is extremely probable that the rock described as whin was really limestone, as this misinterpretation very often occurs.

On the supposition that the limestone occurs between these two sandstones, its outcrop must run across the northern part of the dam which has been formed on the Thornliebank Burn, and there is nothing to indicate that it does not do so. The sandstone, which forms the fall at the head of the Rouken Glen, must be the same as the one last referred to, and therefore the Giffnock. We have not been able to find any evidence of the fault which has been drawn with a dotted line in the plan accompanying Mr. Macnair's paper on "The Geology of the Rouken Glen,"* and which has been shown as crossing the Thornliebank Burn a little below the fall. On the contrary, we believe there is an uninterrupted section from the fall right up to the position of the lower band of limestone. This band occurs in the bed of the burn about 900 feet due south from Thornliebank House, and, roughly, 150 feet south from where the bands of limestone occur, to which attention has been drawn by Mr. Macnair. It is about a foot thick, and can only be seen when the burn is low. This band we interpret as the Lower Orchard Limestone. The interval from it down to the fall is almost entirely occupied by sandstone. There is a thin coal just below the limestone which we take to correspond with the coal immediately below the Orchard Cement at Orchard itself, while a little further down is a thin coal, which corresponds very well with the coal and blaes 1 foot 6 inches thick seen a little below the Orchard Limestone in the section of Waukmill Glen.

Above this limestone, representing the position of the Lower Orchard Limestone, comes a slight gap in the section, but by protraction it is easy to tell the thickness intervening between it and the lowest band of the limestone which has been described by Mr. Macnair. We estimate the interval to be about

* *Glas. Geol. Soc. Trans.*, vol. xii., p. 362.

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4 fathoms, the upper part of it, at any rate, being occupied by blaes. The second limestone we regard as the Upper Orchard, exactly as it was shown on Captain Stewart's plan. Above it comes a further thickness of blaes, with one thin limestone band, and then sandstone. The accompanying vertical section (H, Plate VII.) will show how well these bands of limestone correspond with the limestones which we regard as representing the Orchard positions in the Salterland No. 2 Bore (E).

Coming now to the ground a little further to the east, the supposed presence of two separate limestones at Whitecraigs was at one time regarded as a difficulty in accepting our present theory as to the number of limestones between the Cowglen and Arden (see Fig. 3). It was supposed, and as we think quite correctly, that the limestone which occurs at the roadside south of Whitecraigs House is the Hole Burn band. If, then, the limestone which was formerly exposed at Whitecraigs Station is a higher one, it must be the Orchard, and, as the Whitecraigs Station Limestone had quite a different character from either of the bands in the Rouken Glen, these must form a separate horizon presumably higher than the Orchard. We shall try to show, however, that the disposition of the limestones can be quite well explained in accordance with our present theory.

In the first place, on the assumption that the outcrop of the Lyoncross Limestone runs across the north end of the dam on the Thornliebank Burn, as mapped by us, the general strike of the strata would make it reach the railway cutting just about the place where a limestone was actually exposed. In the second place, the coal, which was worked to a small extent at a point beneath the railway bridge to the south of the dam, is not too far below the position of the limestone to be the Lyoncross Coal. Lastly, it can be proved that the limestone at Whitecraigs Station is the same as the one south of Whitecraigs House.

The sandstone which overlies the limestone at Whitecraigs Station can be seen on both sides of the cutting, and is, approximately, horizontally bedded. From the south side of the cutting it is only 200 feet to the north-east corner of the plantation, which is occupied by Whitecraigs Quarry, and at

that point another exposure of sandstone is to be seen. At first sight the sandstone here appears to dip to the north, but on further investigation this is seen to be due to false bedding, and the actual lie of the strata can be seen quite clearly to be horizontal. Thus, this exposure of sandstone must be the same as the one in the section at the station. Sandstone is again seen just within the main gate to the grounds of Whitecraigs House, and from there it can be traced step by step south to the house itself, behind which is a lovely glaciated

Fig. 3.

surface. From thence it stretches southwards, forming the crest of a little hill. There is nowhere room for other beds to come in, and it is quite certain that we are dealing with the same sandstone all the way from the station to the south part of the grounds of Whitecraigs House.

This is not, however, the same as the one which was mainly quarried. There is quite a considerable gap between the exposure referred to at the north-east corner of the plantation and any part of the quarried face. We were informed by the gardener at Whitecraigs House that blaes underlies the sandstone which occurs in the grounds, and he showed pieces of

limestone which had been dug up from this blaes just beneath the house. Somewhat further to the south this limestone is actually seen close to the side of the road in the place where Captain Stewart recorded it, and where it is agreed that it is the Hole Burn Limestone. Only a small exposure is now seen, and it might be regarded as an erratic but for the fact that an unsuccessful attempt was made to remove the block. From its position, from the configuration of the ground, and from the dip, which is here easterly, it is quite evident that this limestone *underlies* the sandstone on the hilltop to the east, and *overlies* the main sandstone of the Whitecraigs Quarry. Thus, its outcrop must run, as it has been sketched, across the northern part of the Whitecraigs Quarry plantation, and it must be the same limestone as was formerly seen at Whitecraigs Station. Thus, according to our view, there is no doubt that the limestone discovered there was really the Hole Burn or Lyoncross, and that the sandstone above it is the Giffnock.

Further to the east the mapping adopted by us is substantially that which was shown in the map published by Captain Stewart, and we wish again to express our very great indebtedness to him, not only for the assistance which his map afforded, but for personal help and for the communication of a large number of bore journals which he kindly made to the Survey.

We have deviated from his mapping in one respect in regarding the limestone which was found in a well at Cleuch Farm, 1 mile west of Busby, as being the Cowglen instead of the Lyoncross. The somewhat pebbly sandstone which is seen in a quarry N.W. of the farmhouse resembles more closely the sandstone above the Cowglen than the Giffnock. Also a specimen of the limestone which Captain Stewart himself showed us seemed to be more like the nearest exposure of Cowglen Limestone than the Lyoncross. Further, it must be noted that the strike of the Lyoncross Limestone on both sides of Cleuch would carry it further to the north, as is shown in our present map.

Eastwards, beside the viaduct which carries the railway across the White Cart close to Sheddens, a very fine exposure of the pebbly sandstone is seen, where it evidently overlies the

Cowglen Limestone, which is exposed lower down, in spite of the fact that the structure is complicated by one or two small faults.

Coming now once more to the north side of the basin, we regard the two bands of limestone, which have been found in the grounds of Thornliebank Print Works, somewhat to the north of the position of the bore which we have already discussed, as being a continuation of the Orchard horizon. The lower one is more probably the Orchard band itself. It is desirable to point out here that the evidence as to the number of limestones rests mainly on the mapping of the ground to the west, and on the correlation of the Waukmill Glen section with the sequence of strata in the Salterland, Arden, and Thornliebank bores. In the part of the district with which we are now dealing all we can say is that there is no evidence against our view, at any rate, so far as the stratigraphy is concerned.

Further north, as well as to the east, the mapping of Captain Stewart has been substantially followed. It is important to note that the coarse sandstone which comes between the Cowglen and Lyoncross occurs in this part of the ground as well. A large part of Pollokshaws is built upon it, as was shown when the shafts and tunnels in connection with the White Cart purification scheme were in progress. It must be interrupted by the big fault west of Pollokshaws, whose existence was first surmised by Captain Stewart, but it occurs again in a railway cutting about 2000 feet S.W. of Pollokshaws Station. It was also formerly visible just south of the White Cart, and can be seen in a line of old quarries to the south of Cowglen.

We may record here the occurrence of a limestone which was met with in the White Cart purification tunnels close to Millbrae Bridge. The section was as follows:—

	Feet.	Inches.
Sandstone, - - - - -	-	-
Blaes, - - - - -	5	0
Limestone, - - - - -	2	0
Blaes, - - - - -	2	0
Limestone, - - - - -	2	0
Blaes, - - - - -	8	0
Coal, - - - - -	1	3
Blaes, - - - - -	5	0
Sandstone over - - - - -	20	0

From its occurrence in two bands with a coal seam beneath, it may reasonably be correlated with the Lyoncross Limestone.

It is no part of the present paper to describe in detail the Upper Limestone succession here advocated in the country N. of the Clyde, but it is of interest to note that a similar succession is there present. Many deep bores have been put down N.E. of Glasgow from, or from above, the Arden Limestone, right through to the Possil Coals beneath. It may be said generally that these bores show that the interval between the Arden and Cowglen Limestones is there divided into three approximately equal divisions by two limestone bands, and that the upper of these two bands, which we would refer to the Orchard, is usually characterised by a thick blaes above it, while the lower (*i.e.*, the Lyoncross) usually has a fairly thick coal (or two coals close together) 3 or 4 fathoms beneath.

These bores all show a good development of the Bishopbriggs Sandstone overlying the Cowglen, and demonstrate the remarkable persistence of this horizon. Other thin limestones sometimes appear, but are decidedly impersistent, and in the main the strata conform to the sequence described above.

Full journals of the bore and stream sections included in our table are being lodged in the Society's library, with the exception of G, which has been published (see footnote, p. 135), and I, the journal of which has already been lodged by Captain Stewart. Bores which have numbers attached to them in the map which accompanies this paper are also in Captain Stewart's list, with the exception of Salterland No. 2, which is included in our own table of vertical sections.