The Results of the Balfour Bore, Fifeshire.. By J. S. GRANT
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THE Balfour diamond bore was started in the year 1902 from a position not far below the top of the Millstone Grit, in order to test the presence and thickness of the coal seams of the Carboniferous Limestone Series in that part of Fifeshire. The latitude of the borehole is $56^{\circ} 11' 15''$ N., and the longitude $3^{\circ} 4' 45''$ W. It was finished in the year 1907, having by that time attained the depth of 4534 ft., and being the deepest bore in Britain. The cores have been examined, and the bore-journal checked, by Mr D. Tait of the Geological Survey.

The first material to be passed through was glacial sand and gravel overlying a layer of boulder clay. At a depth of 8 fms. solid rock was met with. From that point down to 110 fms. the bore pierced a series of massive sandstones, some of which were gritty or even pebbly in texture, separated by faky layers and beds of fireclay, the whole having the typical character of the Millstone Grit as developed in Scotland. The Glenboig fireclay position is absent, but at 112 fms. a thin encrinital limestone was met with, which is regarded as the equivalent of the Roman Cement of the Glenboig district and the Curdly Ironstone.

Twenty fms. below this level is a limestone 8 ft. in thickness, which is correlated with the Levenseat Limestone, and marks the top of the Carboniferous Limestone Series.

Another thin limestone was found 10 fms. below the last-mentioned seam, the intervening strata being blaes. Beneath comes a varying sequence of sandstone, fakes and blaes. A thin limestone occurs at 167 fms., a thick black-band ironstone at 185 fms., and a thinner black-band ironstone about 10 fms. lower down. A limestone in two parts about 5 ft. in thickness was met with at 237 fms., and a coal seam 2 ft. 4 in. thick at 276 fms. One opinion might be that all these seams come above the horizon of the Janet Peat or Arden Limestone, which might be placed at the base of a thick limy blaes occurring between 305 and 316 fms.² Whatever view be adopted as to

¹ Cordial thanks are due to Mr John Gemmell, Mining Engineer, for valuable assistance in the preparation of this paper.

² Mr Gemmell thinks that the coal seam 2 ft. 4 in. thick is the Janet Peat Coal, and he places the horizon of the limestone at 260 fms. If this be the correct reading, the thick blaes just referred to corresponds extremely well with the Orchard blaes, which is so widely represented in the West of Scotland.

its horizon, it seems certain that the bed of limestone itself has disappeared.

A coal in three divisions at 349 fms. may represent the Thick Coal of the Ceres coalfield. Below this seam we find about 45 fms. of strata consisting of sandstone, fakes, blaes and fireclay, and then a coal which is regarded as the equivalent of the Bowersbank Splint Coal of Lochore. The Index Limestone is represented by only a foot of limy fakes occurring at a depth of 407 fms. We thus see that of the three limestones which form main horizons in the Upper Limestone Group (the Levenseat, Arden, and Index seams in descending order), one is absent and one is very poorly represented. Only the highest, or Levenseat Limestone, is well developed, and the same is more or less the case in other parts of Fifeshire, as has long been known.

Only one or two of the coal seams occurring between the Index and the highest member of the Lower Limestone Group can be identified with confidence, but the bore has fulfilled its purpose in showing that a number of coals of very fair thickness do occur in this interval. A coal 2 ft. 3 in. in thickness was met with about 16 fms. below the Index Limestone, and a short distance further down the top of a massive sill of dolerite was encountered. In spite of the difficulty of boring through rock of this description, the bore was continued through a thickness of 77 fms. of this material, after which it again pierced sedimentary strata. A little below this horizon it cut through a bed of volcanic ash mixed with gritty sediment. A coal of moderate thickness occurred at 530 fms., underlaid by a thick post of sandstone. Further down no less than eight thin coal seams were met with in a vertical distance of 30 fms. The Main and Jersey Coals of the Kelty coalfield almost certainly form two of the above eight, but it is difficult to say which two. A further thickness of sandstone and fakes was next encountered resting immediately on one of the thickest coals in the bore section, which is 4 ft. 10 in. in thickness and of excellent quality, and occurs at a depth of 590 fms. This coal has been correlated with some confidence with the Lochgelly Splint, and a thin coal, which is partly a gas coal and has a few inches of black-band ironstone in its centre, at a depth of 3 fms. below the last, is in all probability the Lochgelly Parrot seam.

A series consisting of sandstone with some blaes and one or two thin coals is next passed through, until at 653 fms. the thickest seam of coal in the whole section is met with. Another coal of fair thickness occurs at 664 fms., and almost immediately beneath this position the bore passed through a second sill of dolerite, though small in thickness compared to its predecessor. A short

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distance below this level occurs a thin coal with an inch of black-band ironstone in its roof, but nothing of importance is met with until, at a depth of 704 fms., the last thick coal in the bore section is reached, which seems in all probability to be the Dunfermline Splint.

After passing another coal seam of workable thickness the bore, at a depth of 724 fms., reached the highest thin band of limestone belonging to the Lower Limestone Group. Another thin limestone with a foot of coal beneath occurred at 734 fms. Further down 20 fms. of strata were pierced without meeting a single seam of coal or ironstone, and realising that the coals of the Limestone Coal Group had been entirely passed through, those in charge brought the bore to a close at a depth of 755 fms., or 4534 feet.

The bore affords an opportunity rarely to be met with of studying the effect of a massive intrusion, firstly, as regards contortion of the strata, and, secondly, in its influence on the coal seams above and below. The extent to which the strata are distorted may be seen from the following table, from information supplied by Mr Gemmell. For comparison it may be mentioned that the average dip met with in undisturbed tracts during the boring was about 7° .

Depth.	Dip.
345 fathoms	15°
375 "	22°
390 "	38°
407 "	34°
425 "	54°
431 "	27°
{ 431 "	Top of intrusion
{ 508 "	Base of intrusion
517 "	27°
530 "	31°
550 "	18°
570 "	22°
590 "	13°

It will thus be seen that the intrusion has caused distortion of the bedding for a distance of at least 60 fthms. both above and below. This would seem to indicate that the mass was not injected as a flat sheet but as an irregular body with steeply sloping surfaces.

Regarding the effect of this intrusion on the strata above and below, it may be stated that the thickness of the dolerite passed through in the bore was 77 fms., or 460 ft. The limit of its influence in an upward direction has not been ascertained,

though a coal just above and another 5 fms. above are burnt, but in a downward direction it burnt a coal at 532 fms., or 145 ft. beneath its lower surface. On the other hand, it seems to have had little influence on a coal seam (one of the group of eight referred to) occurring at a depth of 557 fms., or 297 ft. below its base. From this it may be inferred that the effect on the coal seams has ceased at least to be great enough to cause deterioration at a distance from the intrusion of a little more than half its own thickness.

The Millstone Grit in the vicinity of Cameron Bridge is shown by the bore to have a thickness of at least 120 fms., and even if a slight allowance is made for the dip of the strata where influenced by the intrusion, the Upper Limestone Group measures 260 fms. and the Lower Coal Group, including the igneous intrusions, no less than 300 fms. It will enable us to see how much the last figure is above the average if we take for comparison the thickness of the Edge or Lower Coal Group at Niddrie, where it measures only about 170 fms., which is an exceptional thickness for the Midlothian basin. In Glenraig No. 2 bore, near Lochgelly, the thickness of strata from the Index Limestone to the Dunfermline Splint is about 180 fms., and the whole thickness of the Lower Coal Group in that locality is probably about 200 fms. It is significant, however, that the greater part of the thickening shown by the Balfour bore journal when compared with that of the Glenraig bore takes place in the upper half of the group, containing the dolerite intrusion in the former instance. Thus in the Balfour bore the distance between the Index Limestone and the Lochgelly Splint is 160 fms., as against only 70 in Glenraig No. 2 bore. If we subtract the thickness of the intrusion from the former number it no longer shows the discrepancy, while the strata below the Lochgelly Splint are almost the same in thickness at the two places. These figures indicate that the thick dolerite, instead of absorbing the strata has pushed them aside, and that the actual thickness of the Lower Coal Group at Balfour Mains, though greater than in Midlothian, is not much in excess of what it is in other localities in Fife.

A great many of the coals met with in the bore section are coking coals, and it is interesting to note that this remark applies to the Lochgelly Splint, although it is not in this condition in the area to the west.

The bore was put down by Mr Gemmell jointly for the Wemyss Collieries Trust and Mr Balfour of Balgonie. Messrs Thomson Bros. of Dunfermline were the boring contractors, and Mr Donald Manson was the leading borer. The journal of the bore is given under a separate heading, to follow this paper. A

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full account of the bore from the engineering standpoint is given by Mr J. G. Thomson in the *Transactions of the Institute of Mining Engineers*,¹ and some particulars are also given by Mr Gemmell in another paper in the same volume.²

¹ "Deep Diamond-boring at Balfour Mains, Fifeshire," by J. G. Thomson, *Trans. Inst. Mining Engineers*, vol. xxxvi.

² "The Wemyss Coal-Field," by John Gemmell, *ibid.*