

XIV.—The Igneous Geology of the Bathgate and Linlithgow Hills. By J. D. Falconer, M.A., B.Sc. *Communicated by* Professor JAMES GEIKIE, LL.D., D.C.L., F.R.S. (With a Map.)

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CONTENTS.

| | PAGE | | PAGE |
|---|------|---|------|
| Previous Literature | 359 | The Fourth Volcanic Zone, or The Hilderston and | |
| Introduction | 359 | Hilly Lavas | 362 |
| The Houston Coal | 360 | The Index Limestone and the Bo'ness Lavas | 363 |
| The First Volcanic Zone, or The Brox Burn Ash | 360 | The Fifth Volcanic Zone, or The Kipps and Bishop- | |
| The Second Volcanic Zone, or The Longmuir and | | brae Lavas | 364 |
| Riccarton Lavas | 361 | The Dykeneuk and Castlegary Limestones | 365 |
| The Third Volcanic Zone, or The Kirkton and Hill- | | The Volcanic Necks | 365 |
| house Lavas | 362 | The Intrusive Rocks | 365 |
| The Hurlet Limestone | 362 | General Results | 366 |

PREVIOUS LITERATURE.

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INTRODUCTION.

The Bathgate and Linlithgow Hills occupy a well-defined belt of rising ground stretching S.S.W.—N.N.E. from Bathgate to Bo'ness, and included in the marginal portions of sheets 31 and 32 of the 1-in. maps of the Ordnance and Geological Surveys. Throughout the range the steeper slopes face the west, while the eastern flanks are deeply buried in drift. The glaciated contours are well seen from the east, and the sky-line is in several places deeply indented by glacial grooves. The physical geography is throughout intimately dependent upon the geological structure, but the latter is simplicity itself when contrasted with the complicated structure of the shale-fields to the east. Alternating zones of volcanic and sedimentary rocks strike parallel with the direction of elongation of the range from Bathgate to Bonnytown Hill, and these are cut by a later connected series of dykes and sills of intrusive igneous rock. The latter, as a rule, are more resistant than the lavas, and form the more prominent features of the landscape, while the sedimentary intercalations may frequently be traced, even where no rock is visible, by the trough-like depressions which have been hollowed out of them between the zones of lava.

As convenient boundary-lines for the study of these hills, I have chosen as lower limit the final western outcrop of the Houston Coal from Drumcross to Champfleurie, and thence a line drawn directly north to the shore of the Firth at Stacks, and as upper limit the outcrop of the Castlecary Limestone. The accompanying map represents on a reduced scale the 6-in. sheets ix. N.E., v. S.E., v. N.E., i. S.E., i. N.E. of Linlithgowshire, with the eastern halves of ix. N.W., v. S.W., v. N.W., i. S.W., i. N.W. of the same county. I have thought it unnecessary to continue the map to the south of the Bathgate Railway, beyond which the volcanic series rapidly runs out, while the country is so much covered with drift that little rock is visible. The geology below the Houston Coal and above the Castlecary Limestone is simply sketched in from the Survey sheets, and has not been personally verified in detail.

The Houston Coal.

The outcrop of the Houston Coal, crossed by numerous dip faults, has been well proved from Deans to Drumcrosshall. Thence it strikes north by west to the neighbourhood of Blackcraig and West Binny, having been worked many years ago at both of these places. In the vicinity of Ochiltree Mill the outcrop is uncertain, the ground being much faulted and pierced by many intrusions. North of Peace Knowe, however, it reappears and strikes north by west to the Haugh Burn fault, by which it is shifted to the east beyond the limits of the present map.

Between the Houston Coal and the first volcanic zone come the Houston shales and marls, with thin sandstones and occasional beds of ash and agglomerate. Good sections are found in the Mains Burn and the Brox Burn and its tributaries.

The First Volcanic Zone, or The Brox Burn Ash.

This zone can be traced, with interruptions, from Drumcrosshall to the Haugh Burn. It consists throughout of stratified volcanic ash, varying much in texture and usually green in colour, but weathering yellow or brown at Chapelhill and Bankhead. Interbedded lava is nowhere found in this zone, although in places the compact ash weathers spheroidally, and presents a deceptive resemblance to a decomposing crystalline igneous rock. Characteristic sections are found in the Brox Burn and its tributary to the south. On account of the absence of exposures, this zone cannot be traced to the east of the Longmuir plantation. It reappears, however, on the same horizon on the Riccarton road, immediately to the north.

Between this ash and the second volcanic zone there appear some thinly bedded sandstones and shales, frequently ashy themselves, and interstratified with thin bands of ash. These are well seen in the Brox Burn and in a streamlet in the northern angle of the Longmuir plantation.

The Second Volcanic Zone, or The Longmuir and Riccarton Lavas.

This zone is taken to include two apparently distinct groups of lavas. The lower or Longmuir group extends from a point a little to the east of Broomyknowes, through the Longmuir and Balditop plantations, to Drumcross. The upper or Riccarton group is of greater thickness but of less extent, stretching only from the Riccarton Burn to the Rigghead plantation, a little to the south of Tartraven. The two groups are separated by a series of sandstones, shales, and thin ashbeds, well seen in the streamlets and quarries on the northern slope of the Riccarton Hills. Petrographically, the Longmuir lavas are throughout fine-grained olivine-basalts, while the Riccarton lavas can be separated into a lower zone of coarse-grained olivine-dolerites* extending the full length of the group, and an upper zone of olivine-basalts stretching from the Riccarton Burn to North Mains.

This subdivision of the zone is everywhere apparent to the north of the Mains Burn, but to the south so little rock is exposed that the lines are to some extent hypothetical. The sedimentary intercalation between the two groups of lavas cannot be traced by means of actual exposures of sandstones and shales. In consequence, more than usual reliance must be placed upon the prolongation to the south of the petrographical variations established above. The coarse-grained olivine-dolerites of the lower zone of the Riccarton lavas are nowhere found to the south of the Rigghead plantation, beyond which the exposures are all of olivine-basalts similar to the Longmuir lavas to the north. The sedimentary band, apparently reduced in thickness, is therefore drawn, as nearly as possible, between the basalts and the dolerites. Marginal sedimentary intercalations are probably numerous throughout this zone. Two such are shown on the map, one of shales and sandstones found in drains on the farms of Drumcross and Quarter, the other of sandstones, shales, fine-grained green ash, and agglomerate, exposed in the Brox Burn at the Balditop plantation. The sections exposed during the construction of the Bangour reservoir indicated considerable disturbance of the strata at that point. Another thin bed of sandstone, interstratified with the lavas, may be seen immediately to the east of the neck in the Riccarton Hills.

This second volcanic zone cannot be definitely traced to the south of the Galabraes fault, although the section at Starlaw indicates the occurrence of scattered lava-flows. North of Broomyknowes also the lavas rapidly run out, and their place is taken by interstratifications of sandstone, shales, and thin ashbeds, with at least one thin band of shelly limestone exposed in the burn below Riccarton Mill.

Between the second and third volcanic zones there comes another sedimentary intercalation, represented by shales and thin ashbeds at Craigs, limestone and shale at Tartraven, shales and ash in the Riccarton Burn west of Beecraigs, sandstone, shale, and limestone at Whitebaulks, sandstone at Hillhouse, sandstone and limestone at

* The terms "basalt" and "dolerite" are used throughout to denote macroscopic distinctions, "basalt" implying a fine-grained, compact, and usually porphyritic rock, "dolerite" a coarse-grained rock, not evidently porphyritic.

Carsie Hill, east of Cauldhame, and at Peat Hill, on the north side of the Haugh Burn fault.

The Third Volcanic Zone, or The Kirkton and Hillhouse Lavas.

This zone includes the Kirkton, Tartraven, and Hillhouse lavas. A very characteristic ash, with black matrix and yellow lapilli, lies in several places at the base of this zone. It is well seen at Whitelaw, Craigs, Whitebaulks, and Hillhouse. The lavas of this zone can be studied with ease in numerous exposures from Kirkton Mains and Boghall to The Knock. Porphyritic olivine-basalts predominate, but a thin band of dolerites strikes N.W. from the Raven Craig. The limestones and accompanying shales and ash of the east and west Kirkton quarries, so well described in the Survey Memoir accompanying sheet 32, occur as isolated lenticular patches between successive lava-flows, and evidently occupy a much higher horizon than the Tartraven Limestone. A similar intercalation of sandstone may be seen on the eastern slope of the Knock Hill. From the Knock to Tartraven little rock is visible, but numerous exposures are found in the Tartraven Hills where the road cuts through a series of dark-blue lustrous limburgitic olivine-basalts. The lavas of this zone probably run out to the north of the Mains Burn, for in a streamlet to the east of Balvornie the only representative of the zone is the basal ash noted above. This apparently swells out by Whitebaulks to Hillhouse, where it dips below a group of coarse-grained olivine-dolerites, which, after suffering displacement by the Haugh Burn fault, runs out to the north of Parkly Place.

The Hurlet Limestone.

This well-marked horizon can be traced from Glenbare quarry, east of Bathgate, to the North Mine quarry on the Tartraven road. For a mile to the north of this point the outcrop is conjectural, no trace of the limestone being found at the surface. It reappears, however, in characteristic sections in the Hillhouse and Hiltly quarries. North of Hiltly the outcrop must be shifted to the east by the Haugh Burn fault, and probably strikes north from the vicinity of Parkly Place to Linlithgow Poorhouse, and thence north-west to the shore at Stacks. The Hurlet Limestone is throughout associated with sandstones, shales, and thin ashbeds; and detailed descriptions of sections, formerly better visible than now, may be found in the Survey Memoirs and Mr CADELL's papers.

To the east of Linlithgow no volcanic rocks are found below the Hurlet Limestone, within the limits of the present map, and, other than the thick sandstone formerly quarried at Kingscavil, little rock of any kind is visible.

The Fourth Volcanic Zone, or The Hilderston and Hiltly Lavas.

This zone reaches its greatest thickness immediately to the south of Linlithgow, but even here the apparent thickness is greater than the actual thickness, on account of

the effect of the Haugh Burn fault. Petrographically, the zone is composed of a number of alternating bands of olivine-basalts and olivine-dolerites. Transverse traverses in the neighbourhood of Clarendon, Hiltly, Wairdlaw, or Hilderston readily reveal this structure. As a rule, however, these bands cannot be traced far in a north and south direction. A stratified intercalation of ash and ashy shales is found in Preston Glen, and another of limestone and shales at Wairdlaw. The basalt overlying this limestone is noteworthy, both for its platy jointing and for the fact that it is the only lava throughout the whole volcanic series which contains phenocrysts of felspar in any abundance. The same rock can be traced on the south side of the valley at Wairdlaw, but the limestone below is nowhere visible. A line of springs behind Craigmailing probably marks the prolongation to the south of this sedimentary intercalation, and indications of its presence are also found on the eastern slope of Cathlaw Hill. Towards the south interbedded sediments probably become more abundant. Two bands are exposed in the Mavis Glen, and these can be traced for a considerable distance to the north and to the south by means of the shallow depressions between the lavas to which they give rise.

The lavas of this zone cannot be traced to the north of Linlithgow Loch. In all probability they rapidly run out, and their place appears to be taken in part by a thick bed of volcanic ash found in a bore in Bonnytown farm. Farther north the sandstones, shales, and thin limestones of Carriden probably occupy approximately the same horizon.

The Index Limestone and the Bo'ness Lavas.

Between the fourth and fifth volcanic zones there occurs in the Bathgate Hills an important belt of sedimentary rock, which includes the lower Bathgate coals and the Index limestone. It retains a fairly uniform thickness and character from Bathgate to Kipps. North of Kipps, however, the thickness gradually increases, and volcanic material becomes mingled with the sedimentary. On the eastern slope of Cockleroy a bed of ash appears not far below the probable position of the Index limestone, and at Kettlestoun fine-grained volcanic mudstones, passing into ashy sandstones and shales, are found overlying the lavas of the fourth volcanic zone. Between Kettlestoun and Linlithgow Bridge the only exposure is in the river Avon at the railway viaduct, where a very vesicular basalt lies a few feet below the Index limestone. The journals of bores quoted by Mr CADELL seem to indicate that a considerable proportion of the rock below the glacial gravels of this district is of volcanic origin. This change in the character of the strata makes it very doubtful whether the Kipps coals and the Index limestone are continued across Cockleroy to Kettlestoun. It is quite possible, however, that the coals do exist, but almost certainly in an attenuated form, of no commercial value, and much destroyed by intrusive rock.

North of the Edinburgh and Glasgow Railway the Index limestone is repeatedly exposed in the river Avon, while the sedimentary zone, as a whole, opens out rapidly

to include the Bo'ness coalfield and its intercalated volcanic rocks. In one sense, therefore, since mere thickness of strata is in this case no index to rate of deposition, the whole of the Bo'ness coalfield may be considered the equivalent of the lower Bathgate coalfield. On the other hand, from the position of the igneous material where it first appears at Cockleroy and Linlithgow Bridge, the lower Bo'ness coals might possibly be considered more nearly the equivalent of the lower Bathgate coals in point of time. Further, the lavas of the Bo'ness coalfield apparently form a group by themselves entirely distinct from the volcanic zones of the Bathgate Hills to the south. It is highly probable, as Mr CADELL has suggested, that the conditions of sedimentation were entirely different on either side of a volcanic orifice somewhere in the vicinity of Little Mill.

It is unnecessary to describe in detail the stratigraphy of the Bo'ness coalfield. That has been admirably done already by Mr CADELL, and the Little Mill district alone still remains more or less of a puzzle. Petrographically, the lavas of Bonnytown Hill, south of the Roman road, can be readily subdivided into three zones—a lower zone of coarse-grained olivine-dolerites between the Red Coal and the Wandering Coal; a middle zone of porphyritic olivine basalts between the Wandering Coal and the Western Main Coal; and an upper zone of coarse-grained dolerites between the Western Main Coal and the Muirhouse coals. The middle zone alone can be traced below the ash of Little Mill to Pepper Hill and Linlithgow Bridge. To the north the lower zone can be traced continuously to the Bonhead fault, but the two upper zones, north of the Roman road, apparently pass into finer-grained doleritic basalts, which persist throughout the remainder of the coalfield. The rock exposed above Bonsyde is similar to the lavas of the middle zone to the west, and is probably a displaced portion of the other lavas of the hill.

The Fifth Volcanic Zone, or The Kipps and Bishopbrae Lavas.

This zone lies a short distance above the Index limestone, and may be traced, with interruptions, from Linlithgow to Bathgate. Between the Avon Paper Mills and the vicinity of Cockleroy, where this zone reaches its greatest thickness, the only exposure is found in the Cauld Burn at East Belsyde. It is highly probable, however, that this zone is continuous throughout. Petrographically, the lavas belong mostly to types of olivine-basalt, and limburgitic varieties may be studied with ease in the neighbourhood of Kipps. Coarser-grained doleritic types occur here towards the summit of the series, and appear also in the river Avon at Linlithgow.

Above the lavas and below the Dykeneuk limestone evidence of the continuance of volcanic action is found in Carriber Glen, where a thick series of ashy sandstone and volcanic mudstones, in places fossiliferous, are exposed in the gorge of the river Avon. Similar ashy sandstones are found at Threegables, east of Bowden Hill; and in a streamlet between Lochcote and Gormyre a bed of ash occurs on approximately the same horizon, overlaid by a peculiar blue mudstone, which in places much resembles a decomposed igneous rock.

The Dykeneuk and Castlecary Limestones.

The Dykeneuk limestone, though proved in many bores, is seen at the surface in three exposures only—at Dykeneuk, Woodcockdale, and Carribber. The Castlecary or Levensat limestone is exposed at Craigenbuck, at the Birkhill viaduct, the Avon aqueduct, Carribber, Bowden Hill, and Lochcote. Both limestones are probably continuous across Bowden Hill, though in places cut out by intrusive rock. South of Bishopbrae their presence beneath the surface has been repeatedly proved in bores. The strata between the two limestones consist of sandstones and shales, thickest towards the north and thinning out towards the south, with the effect of bringing the limestones closer together from Carribber southwards. No trace of volcanic activity is found above the Dykeneuk limestone.

The Volcanic Necks.

These are found in the eastern part only of the volcanic area. A small neck full of green ash pierces the Riccarton Hills south-east of Belcraigs. Another, full of coarse agglomerate, breaks through the stratified ash of the first volcanic zone to the west of Wester Ochiltree. A group of seven small necks is found in the neighbourhood of Hiltly and Parkly Place, some filled with coarse agglomerate, and others with fine-grained ash similar to that at the base of the third volcanic zone. The Necks of Pilgrim's Hill and Carriden are also included in the accompanying map.

The Intrusive Rocks.

The intrusive rocks of this district are readily separated into two groups according to their microscopical characters,—a smaller group of olivine-basalts and dolerites, and a larger group of augite diabases, with little or no olivine, but with frequently abundant hypersthene. An intersertal microlitic or micropegmatitic groundmass is usually present in the latter, in greater or less abundance. This difference in mineral composition seems to be most easily explained on the assumption that the two groups are the products of different periods of igneous activity. The smaller and more basic group might readily have been produced from the consolidation of igneous material similar to that which produced the lavas. They may therefore be regarded as more or less contemporaneous intrusions. The large group, however, is of a more acid character, and is certainly the product of a later period of igneous activity.

(a) *Contemporaneous intrusions.*—Small intrusions of olivine-basalt are found in many of the Necks enumerated above, but, other than these, few contemporaneous intrusions have been recognised throughout the volcanic zones. A small intrusion of olivine-basalt cuts the ash of the first volcanic zone in the Brox Burn near the Bangour reservoir. A short dyke of similar material occurs in the third volcanic zone north-

east of Wairdlaw, and another at Haddie's Walls in the Kipps coalfield. The small dyke piercing the lava-cliff to the west of Hiltly is probably of contemporaneous origin. Much also of the intrusive rock in the vicinity of Ochiltree Mill, as well as the Walton and Carriden intrusions, may be referred, from petrographical characters, to the first period of igneous activity.

(b) *The later intrusions.*—These may be subdivided into two groups:—

1. Dyke-like intrusions with a vertical or highly inclined junction—

E.g. The Raven Craig, the Knock, the Witch Craig, the Wairdlaw and Cockleroy intrusions, and the E.-W. dykes.

2. Sills or laccolitic intrusions—

E.g. The Kettlestoun Hills, the Belsyde Hills, and the Torphichen Hills.

The similarity in petrographical type of these intrusions indicates contemporaneity of origin in late or post-carboniferous times. Strict contemporaneity, however, is not implied, the intrusions having evidently been inserted in succession during the period. Those intrusions with a N.-S. elongation are probably oldest, being cut, as in the case of the Raven Craig, by the E.-W. faults, along which dykes have usually risen. These dykes are apparently the feeders of the sills, the lowest and oldest of which are sometimes covered by the feeders of the higher and younger. The upper limits of the dykes themselves were probably irregular, different portions of the same dyke rising to different levels. The upward termination of one of these dykes is particularly well seen at Broomyknowes and Belcraigs. This may explain in part the discontinuity of outcrop of some of these dykes when traced from east to west. In other cases, however, as in the Parkly Craigs dyke, the different portions seem to run out, the dyke being continued on a parallel line a few yards to the north or south.

GENERAL RESULTS.

1. The lavas of the Bathgate Hills are olivine-bearing from base to summit of the series, and are pierced by a few contemporaneous intrusions of similar material.
2. The Bo'ness lavas form a group entirely distinct from the lava-zones of the Bathgate Hills.
3. The volcanic zones are crossed by a later-connected series of dykes and sills, probably of Palæozoic age.

The detailed results of the microscopical and chemical analysis of the rocks are reserved for a future paper.

