THE IGNEOUS GEOLOGY OF THE BURNTISLAND DISTRICT.

by

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INTRODUCTION.

The district examined in the course of the research embodied in this paper is the south-eastern part of the county of Fife, lying between the coast towns of Aberdour and Kirkcaldy, and stretching inland to a roughly semicircular boundary enclosing Auchtertool, Raith and Chapel. The area contained within these limits is approximately thirty square miles, and was mapped on a scale of six inches to the mile, thus embracing the major portion of Sheet 36 and all of Sheet 37 of the 1864 edition of the maps of the Geological Survey on that scale. The revision of the area lately commenced by the Survey will, on account of an alteration in the numbering of the maps, be indicated on part of Sheets 35 and 39, and all of Sheet 40. The results of the present examination of the igneous geology of the area are reproduced at the end of this paper on a scale of two inches to the/

the mile, thus reducing the map to the minimum size consistent with the distinct indication of the rock types represented.

The object of this investigation was to examine the microscopic characters and field relationships of the igneous rocks which have made the coastal part of this region for long a classic ground for the study of Carboniferous Puy phenomena. As is indicated in the next section, previous investigations had been confined largely to generalised descriptions of field occurrences and characteristics. Apart from the preparation of a detailed record, it was hoped that the great thickness of lava-flows to the north-east of Burntisland might yield to a process of zoning, that a thorough acquaintance with their types might make the identification of intrusions more readily possible, and that further information might be gained regarding the relation of the volcanic necks to the general scheme. Finally it was desirable that the position of the South Fife vulcanicity should be shown with regard to the similar outbreaks in/

in adjacent areas.

PREVIOUS INVESTIGATIONS.

The coast section east of Burntisland attracted attention early, and Dr. P. Neill gave a short note on the lava-flow sequence there exposed in his translation of Daubuisson's "Basalts of Saxony". (Edinburgh 1814. Note facing page 215.)

A further description of the same exposures was given by Ami Boué in his "Essai Géologique sur l'Ecosse". (Paris about 1820. Page 471.)

Charles Maclaren also mentions them in "The Geology of Fife and the Lothians". (Edinburgh 1839. Pages 82 and 107.)

A very full account of the igneous geology of the district under consideration is to be found in Sir Archibald Geikie's "Ancient Volcanoes of Britain". (London 1897.)

The work of H. M. Geological Survey in this area is described in the memoir on "The Geology of Central and Western Fife and Kinross". (1900), Sir Archibald Geikie contributing several chapters on the igneous/

igneous phenomena. Little is said regarding the petrology of the rocks, although an examination of sections from certain localities was made by Dr. F. Hatch, Professor Watts, and Professor H. J. Seymour.

In 1907 Dr. R. Campbell and Mr. A. G. Stenhouse placed on record their research on "The Geology of Inchcolm", an island to the south-west of this region. (Transactions of the Geological Society of Edinburgh, Vol. IX, page 121.)

In 1910 Dr. C. A. Matley published a preliminary note on "The Lower Carboniferous Rocks near Aberdour (Fife)", in which he mentions briefly some of the members of that suite. (Transactions of the Geological Society of Edinburgh, Vol. IX, page 364.)

The most recent work in the area is by Dr F. Walker who mapped and examined the two sills immediately surrounding the town of Aberdour, beyond the south-west corner of the appended map. (Transactions of the Royal Society of Edinburgh, Vol. LIII, Part II, No 18, page 55.)

GENERAL GEOLOGY/

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The rocks of the area lie in the form of an anticline with its core a little to the west of Burntisland, and pitching slightly to the east of north, being in fact the northward continuation of the Pentland fold. The lowest beds revealed at Burntisland consist of sandstones, shales, and thin impure limestones which are not, however, of the usual cementstone type. Above these occurs the equivalent of the Burdiehouse Limestone – a threefold deposit separated by arenaceous bands. A hundred feet of Grange (Dunnet) Sandstone follows, and is succeeded by the Dunnet Shale, once worked for oil production. The next horizon, the Binny Sandstone is represented by a fairly continuous scarp, and above it is an oolitic limestone which is taken as the one usually associated with the Fells Shale elsewhere. A thin coal seam, correlated with the Houston Coal of the Lothians, was met with still higher in the course of the mining operations of the Burntisland Oil Company.

The/

The normal process of sedimentation indicated by these deposits was interrupted shortly after the coal was laid down, for volcanic activity commenced and sheet after sheet of lava and tuff accumulated, punctuated by periods of quiescence when beds of sandstone, shale and limestone were deposited over irregular areas. These indicate in a general way the progressive submergence of the land, culminating in the formation of marine limestones of the First and Second Abden horizons. The outpouring of lava entirely ceased before the Hurlet Limestone was laid down, so that this phase of igneous activity did not persist beyond Calciferous Sandstone Times. These lava-flows, amounting to some fifteen hundred feet in thickness, follow the structure of the anticline, but confine themselves in the main to the eastern limb, only a few extending so far westwards as to pass round the apex of the fold.

On the western limb of the anticline, which is characterised by a gentler dip than the eastern, the deposits between the Burdiehouse Limestone and the/

the Hurlet Limestone are almost entirely sandstones, with a considerable development of tuffs as we approach the terminations of the lava-flows.

Volcanic necks occur throughout the area, the two largest being the Aberdour crater and the Binn at Burntisland, which are situated on the flattened core of the anticline about one-and-a-half- miles apart. From these to the small pipes filled with ash, there are many gradations in size.

A few dykes have been noted, but by far the majority of the intrusions are sills. Three of these invade the beds below the Burdiehouse Limestone at Burntisland, with offshoots to the east and to the west. To the north and north-west there is a most striking development of sills, which follow in a general way the outcrop of the Hurlet Limestone, and cover a superficial area about equal to that of the lava-flows to the east.

TOPOGRAPHY.

The surface features of the region reflect to a marked extent the rocks and rock-structures to which they/

they owe their being. That area over which the lava-flows have been developed is plateau-like, with intercalations of sediments indicated by depressions following the line of strike. This structure is lost in the western or sedimentary zone where numerous intrusions have furnished irregular areas of more resistant material, thus producing greater diversity of surface features.

The coastline, where it has cut into the lavas, is characterised by cliffs, no matter whether the section follows the dip or the strike. The sediments below the Burdiehouse Limestone at Burntisland have yielded a small low-lying coastal strip, protected by the three sills which are responsible for the triple ridge upon which the town is built. To the east, where these sills die out, this flat has lost more than half its area since the commencement of the seventeenth century. Much of the corresponding area to the west would be flooded were it not for reclamation schemes. To the west of Burntisland the coast follows the strike of the sediments/

sediments and a step-like rise of the land surface can be noted. Several sills give strength and support to these structures.

Inland, the lava-flows and to a greater extent the intrusions give rise to long hill ridges which can be clearly traced round the apex of the anticline. The necks, as such, contribute but little to the topography, but where the agglomerate has been pierced by intrusions their resistance to weathering may once again make a crater a hill-feature. For example, the prominence of the Binn at Burntisland is purely fortuitous, three factors having contributed to present it to our eyes as a type section of a neck. It lies at the southern edge of the lava-flow plateau; it is buttressed within and behind by dykes of basalt; and the sediments in front have been readily eroded away.

There are no conspicuous river courses in the region, the annual rainfall not being great and the cachment area small. Diminutive streamlets abound, and it is noticeable that, in the lava-flow zone/

zone immediately behind Kinghorn, they are not deflected by the strike changing, but maintain an easterly direction to the sea, occupying depressions of a glacial origin. East-west dry valleys and windgaps are not uncommon. Of glacial boulders few instances are to be seen, largely owing to intensive cultivation for many decades and to the extensive use of loose blocks in the building of "dry-stone-dykes", most of the older farm and field boundaries being of that nature. Nevertheless there is plenty of drift in the hollows, and for this reason the nature of the sediments intercalated between the lavas can but rarely be determined once the shore section is left.

Material for examination can be readily obtained from the steep scarps of most of the igneous outcrops, which generally carry small plantations. The summits of many of the irregular boss-like intrusions are often devoid of soil except in scattered patches, and from these, too, specimens can/

can be collected in all stages of decomposition. On the whole, however, fresh material is fairly plentiful, and natural exposures are throughout the area frequently augmented by railway cuttings and quarries for road-metal. The extent of softer rocks such as tuffs could only be traced in many cases by an examination of the bottoms of deep furrows on the back of ridges — a practice which can hardly be expected to yield final results.

The detailed results of this investigation will be considered in the order in which the phenomena are believed to have occurred — first the necks, then the lava-flows, and finally the intrusions. Petrographic details are included under the appropriate heads.

VOLCANIC NECKS.

The Binn, Burntisland.

This old volcano forms the prominent hill immediately behind Burntisland. It possesses two summits, the major one rising to a height of six hundred and thirty two feet above sea level, and these correspond to the twin necks which constitute the mass. Between them extends a turf slope near the top of which is an outcrop of thin-bedded granular tuffs. Near the bottom of the slope, at its eastern end, sandstones can be found in place. This slope with its well defined sediments suggests that the two necks are not in contact. The west vent has a diameter of about three hundred yards while the east measures some six hundred yards across. The distal margins of the necks while not exposed can be determined with a fair degree of certainty, there being in each case but a short distance between the surrounding sediments and the ash. The northern limits cannot be beyond the old/

old limestone quarry to the north of the Binn, but those to the south are less easily distinguished. In the absence of clear marginal exposures it is impossible to determine the angle of inclination of these two necks either to the surrounding strata or to each other, but they are apparently vertical. The horizons cut by the Binn necks can be clearly demonstrated, for to the east beside High Binn village is a quarry in which the Binny Sandstone was worked. To the west, immediately beyond the ash are a series of quarries in which the Dunnet Sandstone and Burdiehouse Limestone positions can be seen.

As Sir Archibald Geikie has given a full description of the general appearance of the Binn volcano in the memoir on "Central and West Fife", there is no necessity to repeat it here. It will suffice to state that the vents are filled with a fine gray ash, often showing well developed orbicular weathering/

weathering, and lying in elongated rounded masses which sometimes show parallel orientation and inclination. Calcite is abundantly developed in veins throughout, and is occasionally accompanied by siderite. In this matrix there is a profusion of bombs, which vary in size from small pebbles to large boulders. The larger fragments are blue basalts, often highly vesicular, and with a weathered surface which may be either bright red or gray. In these the remains of olivine phenocrysts can be identified, usually without the aid of a lens. Rounded pieces of limestone are next in order of numerical superiority although they form a minute percentage of the bombs compared with the basalt. They are small in size, and of a compact dark gray variety which develops a white crust. Thin-bedded clay rocks with a calcareous cement contribute a little to the total. A general rounding of these fragments is noticeable. Pieces of shale are not uncommon, and in them and in a few of the limestones organic remains can be found. Sandstones contribute exceedingly little to the agglomerate./

agglomerate. Some fragments of well-bedded granular tuff occur.

In the east neck of the Binn, in the sandstones to the east, on the turf slope between the craters, and in the area lying immediately to the north are several intrusions of very dark compact basalt in which small olivine phenocrysts can be readily seen. These intrusions tend to assume the form of sills among the sediments, but where ash is the surrounding medium they occur as narrow dykes elongated vertically, and almost invariably show columnar jointing developed at right angles to the surface of contact. No intrusions have been located in the west crater.

Kingswood Neck.

This neck is exposed on the north side of the main coast road about a mile east of Burntisland. The exposure indicates a diameter of some two hundred yards/

yards, but the margins are concealed. There are sandstones to the east and to the west of the ash, and their dips while complicated by faulting are directed locally towards this volcanic feature. The neck is apparently vertical and the horizon truncated is in the neighbourhood of the Burdiehouse Limestone. The sandstones in all likelihood belong to the Dunnet or the Binny horizon, for there is no considerable development of such rocks in this area for hundreds of feet above the Houston Coal.

The ash is similar to that of the Binn. In the western part it is singularly free from bombs, but to the east basalt boulders are common. Near the centre is a curious vertical pillar of tuff which has resisted weathering much more successfully than the remainder. This may be due to the presence of a dyke further in but no exposures of that nature have been located, and the basalt found in the detritus probably originated from bombs.

King Alexander's Craig Neck./

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This is a small crater, with a diameter of about seventy yards, which is exposed on the maincoast road about a mile and a half east of Burntisland. At its western margin the neck truncates lava-flows, tuffs, shales and some thin limestones which have a general north-eastward dip. The apparent eastward dip is about ten degrees, yet the crater margin is practically perpendicular. Near the junction the various sediments have developed an abrupt inclination towards the neck. The eastern margin is not clearly exposed but a basalt outcrop occurs near the roadside lying in a horizontal position.

Throughout the gray ash which fills the vent are numerous bombs, the majority of which are basalts of the Dalmeny type. They are roughly rounded and have a red weathered crust which often shows spotting. Rounded pebbles of a compact gray limestone are strongly represented, but larger angular fragments of that rock are also found. A compact clay rock contributes many rounded pebbles, characterised by a white/

white weathered crust. These pebbles are slightly calcareous. Pieces of shale are scattered throughout the ash, and one or two fragments of a granular sandy limestone. Sandstones are rare. In one part of the neck are some thin bands of regularly bedded fine-grained tuffs.

Aberdour West Neck.

In the L. and N. E. R. cutting half a mile east of Aberdour Station is exposed a large neck filled with great rolls of gray ash and bombs. At its western margin are bedded tuffs weathering red, and these have a general easterly dip. For a little over a quarter of a mile the cutting is through ash and then the eastern junction is clearly seen with thin-bedded sandstones, claystones and limestones dipping steeply into the vent. The northern limits of this crater cannot be beyond the southern end of Humbie Wood or the small plantation west of Long Gates, for at both places sandstone is exposed. On the other hand volcanic ash was found in deep furrows in the fields/

fields due west of Dalachy. This is sufficient to indicate that this neck has an area probably rivalling that of the Binn. This vent truncates beds around the Burdiehouse Limestone horizon, and is apparently vertical.

In the gray ash of this neck are numerous bombs of compact blue basalt in which porphyritic olivines are clearly visible. Fragments of an exceedingly compact gray limestone, characterised by scattered crystals and veins of calcite occur, and more rarely a coarse granular sandy limestone contributes somewhat angular pieces. Shales and bedded tuffs are also present, the latter having angular fragments of a yellowish colour set in a dark gray matrix.

There are two intrusions of basalt, exposed in the small plantation west of Dalachy, which are probably associated with the neck and are possibly situated within its confines. They are typically compact blue basalts with small but conspicuous phenocrysts of olivine.

Aberdour East Neck./

Aberdour East Neck.

A quarter of a mile east of the large neck at Aberdour, and also exposed in the railway cutting is a smaller feature of a similar nature. A typical volcanic agglomerate is seen for a distance of some sixty yards along the line. It truncates steeply sandstones and allied sediments below the Burdiehouse Limestone horizon and is probably vertical. The neck is filled with a greenish ash which contains much calcite in the form of veins and strings. Some fragments of thin-bedded tuff seem to represent the sole boulder content of the ash.

Balram North Neck.

This neck and the two succeeding ones lie to the north of Humbie Wood, behind Aberdour. The north neck is the largest one as far as can be judged in a somewhat badly exposed area. No actual junctions can be seen anywhere, but sandstones crop out to the north-west and to the south, and dip in the direction of the neck, which is filled with a dark ash full of angular/

angular fragments of a pale yellowish colour. This can be collected from deep furrows upon occasion, over a large part of the fields to the north-east of Balram steading, extending almost to the main road near Montquey Hill. On the west side of the neck is a good exposure of well-bedded tuffs dipping into it at a low angle, and characterised by rusty-red weathering.

Balram Middle Neck.

This neck lies to the south-west of the one just described, immediately west of the farm-steading. White sandstones are exposed to the south, to the north-west, and to the north of the vent, and dip towards it. The ash is dark bluish gray in colour and contains many angular fragments whose sizes vary greatly, but whose colour is reddish or pale yellow. The weathered surfaces are of a vivid ochrous tint. To the north-west of the neck is exposed a mass of fine-grained blue basalt probably of the nature of a dyke or small boss.

Balram South Neck./

Balram South Neck.

The confines of this neck are much more limited than those of the other two, sandstone being exposed to the north, the east and south in close relation to the ash. The material over much of the area is identical with that of the middle neck, but to the south it is rather more evenly bedded and of a grayish colour. It is more open in texture and contains an appreciable amount of lime. Bombs of basalt are sparingly represented in this part of the neck. To the north-west is an elongated ridge of a compact dark blue basalt.

Newbigging Neck.

It is recorded in the Survey Memoir (1) that a neck of fine tuff was pierced in the underground workings at Newbigging, a mile to the west of Burntisland, where the Burdiehouse Limestone was worked. The waste heaps yielded fragments of volcanic ash. On the surface immediately to the east of the old quarry a red-weathering columnar basalt outcrops./

outcrops. This is, however, a somewhat coarser rock than is usually associated with the dykes of the necks, and is a member of a well-defined group of sills to which reference will be made later.

Kilmundy Neck.

The small mass of Kilmundy Hill, half-a-mile to the west of Burntisland, is apparently an oval neck with its long axis measuring some three hundred yards. It is filled with a grayish ash varying in texture from a fine powder to a mass of angular fragments held in a compact matrix. The margins are not exposed but in quarries to the east and to the west the Burdiehouse Limestone was once worked, and the surrounding sediments can be seen. On the older maps a whinstone quarry is indicated at the western end of the hill, but this exposure is now obscured by an extension of the farm buildings.

Kirkcaldy Neck.

While excavations were being made for the foundations/

foundations of the gasometer on the shore at Kirkcaldy, about half-a-mile north of the Tiel Burn, the operations revealed what was taken to be a volcanic neck filled with coarse ash. Unfortunately it is now impossible to see this exposure, and the foregoing note is due to the kindness of Dr. Walcot Gibson who permitted an examination of the Survey's working maps of the area to be made.

Summary.

From the description of the volcanic necks of the area and from a consideration of their disposition as indicated on the map, it will be seen that there are seven vents cutting horizons below the lava-flows. The three necks at Balram, while their age is obscured by the absence of any of the horizons recognised on the coast section, are most probably younger than the earlier flows in view of the general strike of the beds truncated. The neck at Kirkcaldy gasworks is in the Carboniferous Limestone Series and is therefore the youngest actually demonstrated in the district. The King Alexander's Craig pipe certainly cuts/

cuts the preliminary lava-flows, and is apparently vertical while they are inclined to the east. It is unfortunate that its eastern margin is not clearly seen, for if this neck is perpendicular while the neighbouring rocks are implicated in the Pentland anticlinal movements, it must be younger than the Lower Carboniferous. The apparent perpendicularity of the majority of the necks considered is in keeping with their situation on and around the ridge of the anticline.

An examination of the boulders and pebbles found in six of the twelve necks yielded no material of an age demonstrably younger than the Calciferous Sandstone Series. The limestone fragments lithologically resembled the Burdiehouse Limestone, and the few fossil remains found were either carapaces of small entomostraca or material of piscine origin, equally characteristic of that horizon. None of the contents of the Kirkcaldy or Newbigging necks were available for investigation. The three necks at Balram and that at Kilmundy contain only volcanic material./

material. Further consideration of the age of the necks is reserved for a later portion of this paper.

LAVA FLOWS.

In the area examined considerable difficulty is experienced in discriminating between lava-flows and intrusions since the rocks are in many cases identical in composition and texture. The field characters of the effusives have been so fully described* that it will be sufficient to mention here that columnar jointing is admirably developed in many cases. The largest columns are found near the middle of the flows, often resting upon a thoroughly scoriaceous base. Above these major columns a series of divergent smaller columns is sometimes seen, and these usually pass up into a scoriaceous top. A curious twisting of the columns, probably due to movement/

* Footnote: See Previous Investigations, page 3 of this paper.

movement during cooling, is strikingly evident in stratum No. 27 of the coast section. Platy jointing is seen in stratum No. 39. At many horizons there is a strong development of calcite in joint planes.

Some of the basalts exposed on the coast section have been described as pillow-lavas to which they occasionally bear some superficial resemblance. The ellipsoids do not show the tachylite selvages characteristic of true pillow structure. Further it is not uncommon for contraction fissures filled with calcite to pass through a suite of "pillows" in practically straight lines. Having regard to these features it is suggested that the ellipsoidal structure is due to the disposition of the joint planes combined with the effects of weathering. The resemblance that the resulting masses bear to true pillow structure might be indicated by the use of the term pseudo-pillows in this connection.

The lava-flows are in the main rather fine-grained basalts, of a colour varying from dark blue to black, and carrying small phenocrysts of olivine or its replacement products. Porphyritic augite may also/

also be seen in some of the rocks. In these compact basalts the processes of weathering produce a reddish crust. The more scoriaceous members of the suite become greenish or grayish on exposure and are in many cases almost indistinguishable from fine-grained granular tuffs. Fluxion structure can be determined occasionally by the orientation of the phenocrysts. Attenuation of the vesicles is usually confined to the extreme upper limits of the flows.

In the introductory paragraphs a general statement was made as to the disposition of the lava-flows of the Burntisland district. Their extent is indicated in detail on the map at the end of this monograph. Before entering upon a consideration of the variation of the successive flows it is necessary to give an account of their petrographic characters, the criteria upon which subsequent discrimination and deductions are based.

THE PETROGRAPHY of the LAVA-FLOWS.

Mineral Composition.

(a) Phenocrysts:-

Olivine is the predominating porphyritic constituent, and occurs abundantly throughout the sequence. It is generally idiomorphic, both as bipyramids and as long rectangular crystals, and shows the characteristic cracks. Small spinellids such as magnetite and chrome-spinel are sometimes present as inclusions. Decomposition charges the crystals with iron oxide, with the formation of serpentine and iddingsite, the latter being often markedly pleochroic. In the final stages pseudomorphs of carbonates are the only indications of the presence of olivine originally. Occasionally, large skeletal crystals of olivine have been noted. (See Fig. 1).

Augite is strongly developed and is almost invariably idiomorphic. Not infrequently the mineral occurs in polysomatic euhedral crystals- - aggregates of granules separated by slender portions/

portions of the groundmass and surrounded by a continuous rim. These bodies are only partially in optic continuity in most cases. In many of the basalts there is a striking tendency on the part of the augite to develop in strings and glomero-porphyritic clusters. There are two varieties present, the first being pale brown in colour with an absence of zonal structure and pleochroism. The second is a purplish titanaugite, characterised by zoning and hourglass structures. Usually the zoning is confined to a darkening of the rim of the crystal, but in some cases multiple banding is present, the core being of chrome diopside, surrounded by a violet ring, which in its turn is succeeded by a green border. In general the augite of the second group is pleochroic. Twinning on the orthopinacoid is well developed, most often as a narrow central lamella with broad flanks, but sometimes as a series of nearly equal multiple twins. Inclusions of iron oxide are fairly common.

<u>Felspar</u> occurs exceedingly rarely as/

as a microporphyritic constituent. The crystals are tabular with well-marked albite twinning and are varieties of labradorite, usually showing zoning. Some felspar xenocrysts have been noted, in a more or less corroded state.

(b) Groundmass:-

<u>Olivine</u> occurs sporadically as small idiomorphic crystals, very often completely serpentinised.

The <u>augite</u> of the groundmass, which is sometimes granular, sometimes prismatic, tends to have a streaky or patchy development. In colour it is generally pale brown, but in pyroxene-rich basalts it tends to be slightly purplish.

<u>Felspar</u> in clear undecomposed laths is plentiful in most of the lava-flows, and varies in composition from acid to basic labradorite. In many of the rocks there are irregular patches of a simply twinned or untwinned felspar, with a refractive index below that of the multiple-twinned varieties./

varieties. It is apparently a member of the oligoclase-andesine series.

Black iron oxide is abundant in practically all the sections examined, either as cuboid specks or as skeletal crystals and feathery growths. While the cubes suggest the presence of magnetite, the light-coloured weathering of the more complicated structures indicates ilmenite.

In most of the rocks examined was found a mineral which has been taken to be analcite. It occurs as a clear substance occupying the interstices in the groundmass, and is completely isotropic in the majority of cases. A turbid variety also occurs in somewhat irregular areas. The glass which is met with in certain of the basalts is brown in colour and often shows the separation of mineral matter. The analcite is sometimes associated with apatite needles, but most generally with zeolites.

Chlorite is abundant in many of the rocks, and while it is undoubtedly a product of weathering in some cases, it is associated with such fresh/

fresh material in others to warrant the belief that it may be at any rate juvenile. Calcite and other carbonates are found as decomposition products. Zeolites are strongly represented in rocks from certain localities, both natrolite and thomsonite being present, although the former is by far the more abundant of the two. Where vesicles occur they are filled with carbonates, chlorites, analcite or natrolite sometimes arranged in concentric rings, while feather-like growths in the centre are by no means uncommon.

Structures.

As was indicated in the previous section on the constituent minerals of the lava-flows, these rocks are all porphyritic, and glomeroporphyritic structure is abundantly developed in the case of the pyroxene (see Fig. 2), although it is found with olivine as well. Where there is a conspicuous quantity of either mineral in the rock such clusters probably represent spheres of crystallisation, but even/

even where the quantity is not great the phenocrysts are generally grouped together. This aggregation has been termed by J. H. L. Vogt the "together-swimming structure" or "synneusis structure".[(2)] Resorption of the phenocrysts is typical of olivine. Fluxion structure is generally seen, both in the arrangement of the phenocrysts and in the parallel grouping of the felspar laths round the porphyritic crystals. Many of the basalts are vesicular to the core but in the thicker flows that structure is confined to the top and the bottom. It is a striking feature of these rocks that the vesicles are in the majority of cases spherical. True ophitic structure is not seen in any of the flows, but with a groundmass in which the pyroxene preponderates over the felspars there is a tendency for the former mineral to mould itself round the ends of the latter.

The absorption of quartz grains is responsible for radiating aggregates of tiny augite prisms in some of the rocks. This "augite eye" structure has been described in certain of the intrusions of East Fife[(3)]. /

(3) East Fife. In the case of one basalt at Pettycur, such an aggregate of augite prisms had a core of clear quartz but was separated therefrom by a zone of brownish glass from which the development of the pyroxene could be traced. In many cases, although the zenolith has been completely absorbed, there is no reason to doubt that the radiating augite prisms owe their origin to this process. (See Fig. 3).

Order of Crystallisation.

In the porphyritic olivine basalts the order of crystallisation of the constituent minerals has been in the case of the phenocrysts olivine first and then augite. With regard to the groundmass, in fairly felspathic types the felspar laths and the augite granules probably developed near each other in point of time, as they project into each other from place to place. In groundmasses which are pyroxene-rich granular augite preceded the felspar. The analcite apparently came in when the cooling rock was of/

of the nature of a net-work of felspar laths supporting the phenocrysts and the granular augites. In some cases idiomorphic analcite is developed in cavities. The concluding stage of crystallisation is represented by the incoming of zeolites.

Classification of the Rocks of the Lava Flows.

As these rocks are without exception olivine-bearing, and as felspar is practically never found as a porphyritic constituent, the remaining diagnostic features are the development of abundant augite phenocrysts, the nature of the groundmass, sub-ophitic structures, and, with very cautious application, general texture. In this connection it is advisable to discriminate between basalts and dolerites, although the latter are only found as intrusives within the area under consideration. It is believed that the most satisfactory results can be obtained from the classification of those rocks characterised by ophitic or sub-ophitic structure as dolerites, while in the basalts such structures are absent./

absent. Practically all the rocks in the district are porphyritic, so that such a structure in no way affects the classification. On the other hand it is generally found that in fine-grained members the augite of the groundmass is almost invariably granular, thus in actual practice confining the term dolerite to the coarser types. It must be admitted that, in practically all the rocks examined, ophitic or sub-ophitic structure cannot be determined in hand-specimen.

The classification employed here was first worked out by Dr. Hatch[4], being later modified to some extent by Professor Watts,[5] and more recently extended by Dr. J. S. Flett[6]. While the indiscriminate propagation of new rock types is hardly a commendable feature of modern petrology, in one case a group of South Fife lava-flows seems to call for specific recognition. This, in accordance with the recognised practice, is indicated by the name of the locality where it is best developed, and the rocks have been designated basalts of the Kinghorn type.

Basalts./

Basalts.

1. Dalmeny Type. (Hatch) A rock with many small phenocrysts of olivine and few of augite and felspar in a fine-grained non-ophitic groundmass of felspar laths and granular augite.(Fig.4)
2. Hillhouse Type. (Flett) A rock similar to the Dalmeny basalts, but with a groundmass containing much more augite than felspar, usually with some residual glass. The augite shows zoning, hourglass structure and twinning.(Fig. 5).
3. Kinghorn Type. A rock carrying many phenocrysts of olivine and augite in nearly equal proportions. The pyroxene, which is slightly smaller than the olivine crystals, is somewhat purplish and has a strong tendency to glomeroporphyritic aggregation. The groundmass is dark and fine-grained, consisting of tiny laths of felspar, granules of augite, sometimes a little olivine, and specks of black iron oxide together with a considerable quantity of uncrystallised base. (Fig. 6).

These/

These three varieties of basalt are well represented in the area under consideration, and their relationship to each other is indicated by transitional types, which for the purpose of mapping have been relegated to the more appropriate group without any implication that they are to be regarded as typical of it. Basalts of the Dalmeny and Hillhouse types are common throughout the Scottish Carboniferous. Rocks of the Kinghorn type have been located by Dr. Falconer in his investigation of the igneous geology of the Bathgate Hills [7], but of them he says, "Compact lustrous basalts, porphyritic with olivine and augite. Brown glassy base is abundant, and the felspar of the groundmass is reduced in amount. When the felspar is almost wanting, the rocks assume a limburgitic character." True limburgites [8], according to Rosenbusch, are ultrabasic rocks carrying olivine, augite and magnetite set in a glassy base. They are devoid of felspar. No fresh specimens of igneous rock found anywhere in South Fife are devoid of felspar, so that there is no reason/

reason to depart from the term basalt. On the other hand, the number and size of the augite phenocrysts are most striking, and they indicate a pyroxene-rich magma certainly variant from that which supplied the Dalmeny type basalts. For this reason it has been singled out for recognition as a distinct type.

A careful examination of the rocks of South Fife has revealed the fact that the majority of them carry in the groundmass small quantities of a clear substance which is isotropic under crossed nicols. It generally occupies interstices between fresh felspars and often carries shafts of iron oxide. There is a clear distinction between this and the brownish, green, or almost black glass of demonstrably rapidly cooled rocks of this district. The exceedingly minute occurrences of this substance renders the application of Evans' cubic cleavage test practically impossible, but with a high-power objective some approach to this characteristic has been observed upon a few occasions. Needles of apatite/

apatite are not abundant in the fine-grained rocks, so that its association with analcite, common enough elsewhere, is lacking. A large number of tests were performed with a view to determining whether this mineral might be sodalite, but the chloride reactions were so slight that a small percentage of apatite would be sufficient to account for them. By way of a control, some specimens of the Traprain Law phonolite were treated under the same conditions at the same time. Under these circumstances the mineral has been taken to be analcite, and much of it is considered to be primary. Lindgren, who first described analcite basalts in 1890 (9), used the name for an olivine-bearing basaltic rock in which analcite was the predominating felsic mineral while felspar was merely accessory. Some of the East Lothian basalts have an analcite content which forms a considerable percentage of the rock. The presence of small quantities of primary analcite is a characteristic of many of the rocks of south-east Fife, but in no case is it in quantity sufficient to justify/

justify the use of the name analcite basalt. That a specimen of the Hillhouse basalt from the type locality was found to carry a similar analcite content, further supports this view.

Having dealt with the nature and composition of the rocks which occur as lava-flows in this district, and having indicated the classification adopted, the coast section from Pettycur to Kirkcaldy can be examined. It has been frequently described in general terms, but few references have been made to its petrography. The numbering given in the Survey Memoir on Central Fife (10) is retained for convenience of reference. Two of the outcrops, No. 46 and No. 65, which hitherto have been regarded as lava-flows, are now mapped as sills. They are teschenitic in character and are closely related to field occurrences whose intrusive nature is readily demonstrated. Reference to alterations of a similar nature in the mapping of the outcrops to the north-west of Kirkcaldy will be made in the section of this paper which deals with the intrusions.

COAST SECTION.

The actual section commences at King Alexander's Craig to the east of Burntisland, but the underlying beds are mentioned here in order to indicate important horizons.

1. Strata below the Burdiehouse Limestone.
2. Burdiehouse Limestone.
3. Camps Shale.
4. Grange or Dunnet Sandstone.

4a. Dunnet Shale - once worked by the Burntisland Oil Company.

4b. Binny Sandstone.

4c. Fells Limestone.

4d. Houston Coal.

The volcanic sequence commences with the next bed which is exposed at the west end of King Alexander's Craig, above the garden of Kingswood End house. From there the section can be followed round the coast to Kirkcaldy.

5. Columnar basalt of the Dalmeny type, but with phenocrysts/

phenocrysts almost large enough to put it in the Craiglockhart type. Porphyritic brown augites are few and small. Fully 35 feet.

6. Intermittent dark shale and sandstone.

7. Basalt which is so excessively vesicular that no microscope sections yielded satisfactory results.
40 feet at East end to 10 feet at West.

8. Shale. About 1 foot.

9. Roughly columnar basalt resembling No 5 in that it is intermediate between the Dalmeny and the Craiglockhart types. Porphyritic augites are scarce. 15 feet.

10. Basalt of a very vesicular nature like No 7. 10 feet.

11. An intermittent band of black shale. 6 inches.

12. Columnar basalt of a finer texture than those preceding it, and approaching the Hillhouse type. Porphyritic augite is scarce. 15 feet to 25 ft.

13. A very vesicular basalt. About 15 feet.

14. Tuffs, shales, fireclays and coal. 12 feet.

15. A basalt of the Dalmeny type, with clusters of small brown augites. 15 feet.

This/

This marks the top of the cliff at the east end of King Alexander's Craig.

16. Black and gray shales. A few feet.

A gentle syncline prevents the exposure of higher members of this sequence until Pettycur harbour is reached. The beds at King Alexander's Craig dip east, while near the sandpits tuffs can be seen with a westward dip. In the railway cutting west of Pettycur the lavas are again inclined to the east.

17. Shales and thin limestones. With 17B about 10 feet.

17A. A fine-grained basalt of the Kinghorn type, with a characteristic development of brown augite with purplish rims. It dies out rapidly to the north. About 20 feet.

17B. Some thin sandstones and shales exposed in the ditch east of Pettycur Harbour.

18. A rather badly weathered coarse Dalmeny basalt with very few porphyritic augites, although one or two felspar phenocrysts have been noted. The top of/

of this lava is full of fragments of shales. 30 feet.

19. Another weathered coarse Dalmeny basalt, but distinguished from No 18 by the presence of a fair amount of porphyritic brown augite. 10 feet.

20. A weathered coarse Dalmeny basalt; augite sometimes glomeroporphyritic. 6 feet.

21. A weathered coarse Dalmeny basalt; augite sometimes glomeroporphyritic. 20 feet.

22. Tuff. 12 feet.

23. Shales, fireclays and thin coals. 4 feet.

24. Sandy tuffs, limestone and shale. About 2 feet.

25. A compact augite-rich basalt from a consideration of which the "Kinghorn Type" (see Page 38 of this paper) as an addition to basalt nomenclature is suggested. 14 feet.

26. Shale and tuff. 3 feet.

27. A basalt with curiously twisted columns, seen at the eastern end of the old inn (now barracks) at Pettycur. This rock is very closely related to the Kinghorn type. 35 feet.

28./

28. Black shales. 14 feet.

29. Coarse sandy limestone with some ash. 1 foot.

30. Shale. A few inches.

31. A basalt of the Kinghorn type but rather richer in felspars than usual. 45 feet.

32. Another Kinghorn type basalt but with a tendency towards the development of microporphyritic felspar. 25 feet.

The upper limit of this flow is just to the east of the garrison cottages, and beyond it is a sandy gap strewn with boulders. For about twenty feet nothing has been found in situ.

33. A basalt of the Dalmeny type with an exceptionally fine-grained groundmass, and carrying a fair number of small augite phenocrysts. 30 feet.

34. A basalt of the Dalmeny type with a strong tendency to the development of microporphyritic felspar. 40 feet.

35. Ashy sandstone and shale. These sediments are responsible for the narrow creek at the foot of the little side road to the sea, south of the Kinghorn/

Kinghorn Ness Battery. 8 feet.

36. A basalt possessing strong affinities with the Kinghorn type. 25 feet.

37. Sandy shale and tuff. 8 feet.

38. A basalt of the Hillhouse type but slightly coarser than is usual in a rock of that description. 12 feet.

39. A basalt of the Dalmeny type with a fine-grained groundmass.(11) This rock has a peculiar lenticular development of joint planes. 25 feet.

40. Brick red clay or bole. The erosion of this produces a marked groove on the east side of the cove in which stands the inner tide gauge. A few inches.

41. A basalt of the Dalmeny type. In the groundmass there is a tendency for the augite to mould itself round the ends of the felspars. 25 feet.

41A. Coarse tuff. A few inches.

42. A fine-grained basalt of the Dalmeny type. 15 feet.

43. A coarse Dalmeny basalt, with a groundmass like that of No 41. It is in this flow that an interesting/

interesting assemblage of pebbles occurs. (See Page 93 of this paper). About 70 feet.

43A. Ashy shale. A few inches.

44. Columnar basalt of the Dalmeny type, with a fine-grained groundmass. This forms the striking ridge of Carlinghead Rocks on the south side of Kinghorn Bay. 20 feet.

45. Sediments, the removal of which is considered responsible for the formation of Kinghorn Bay. Near the top of this series, and exposed on the north side of the bay, is a bed of gannister containing numerous stigmaria roots. 230 feet.

46. Immediately above the last-mentioned sediments is a rock of teschenitic characters (See Page 60 of this paper) which is interpreted as a sill although no transgressive junction has been noted. It is thoroughly compact and even to the unaided eye is coarser in texture than the basalts. It has apparently been readily affected by weathering. In composition and structure this rock is very similar to that of strata No 65 and No 69A hereafter described. About 20 feet.

47. Thin ashy shale. 1 foot.

48. A basalt of the Dalmeny type richer than usual in microporphyritic felspars. This rock is badly weathered. 18 feet.

49. Sandstones and shales with plant remains, well exposed in the north wall of Kinghorn Shipyard. 20 feet.

50. Another badly weathered basalt whose characters suggest a coarse specimen of the Dalmeny type. 18 feet.

51. Quartzite of very variable thickness. Average about 2 feet.

52. This probably includes three lava-flows, there being two occurrences of intercalated hard sandstones. The middle member is curiously cindery and simulates an agglomerate. There is, however, a gradual transition from scoriaceous matrix to compact basalt Knobs, and no boulders of extraneous material were found. The rock is a coarse Dalmeny basalt rich in felspar. About 180 feet.

53. Sandy shales with thin laminae, and containing plant remains. Ripplemarks are well shown. 14 feet.

54./

54. An exceedingly badly weathered basalt which is apparently of the coarse Dalmeny type. 10 feet.

54A. Red Bole which weathers out to form a groove. A few inches.

55. A roughly columnar basalt of the Hillhouse type. 30 feet.

56. Shales with "bone bed" near the base. 3 feet.

57. Fireclay. 18 inches.

58. Shale with organic remains. 18 inches.

59. Tuffs. 6 feet.

60. Shale with marine remains. 1 foot.

61. First Abden Limestone. The lowest seam is full of the remains of corals, crinoids, etc. 10 feet.

62. Shale and tuff. 3 feet.

63. An exceedingly fine-grained basalt related to the Dalmeny type but with an exceptionally felspathic groundmass. 9 feet.

64. Tuff and Bole. 4 feet.

65. A coarse-grained Teschenite* exposed along the strike for about 650 yards, with an apparent thickening to the north. Its intrusive nature is indicated/

* Further reference to this intrusion is made on page 60 of this paper.

indicated by a meagre transgression revealed in the railway cutting above; by the presence of pieces of tuff, similar to that composing its roof, in the upper parts of the mass where they are suspended in a practically horizontal position; and by the occurrence in one exposure at the base of the cliff south of Seafield Cave of limestone which lithologically resembles that of the Second Abden horizon. This last feature is somewhat complicated by faulting but there can be little doubt that the teschenite is overlying the limestone. About 20 feet.

66. Fine-grained tuffs with well developed "ash-structure". 20 feet.

67. Shales and fireclay.

68. Second Abden Limestone dislocated at several points by small dip faults.

69. Shales and red sandstones with one thin seam of coal.

69A. <u>Teschenite sill</u>* which shows transgression, two tongues/

* Further reference to this intrusion is made on page 60 of this paper.

tongues being developed in the seaward direction.

70. The Hurlet Limestone with shale, coal and fireclay at the base.

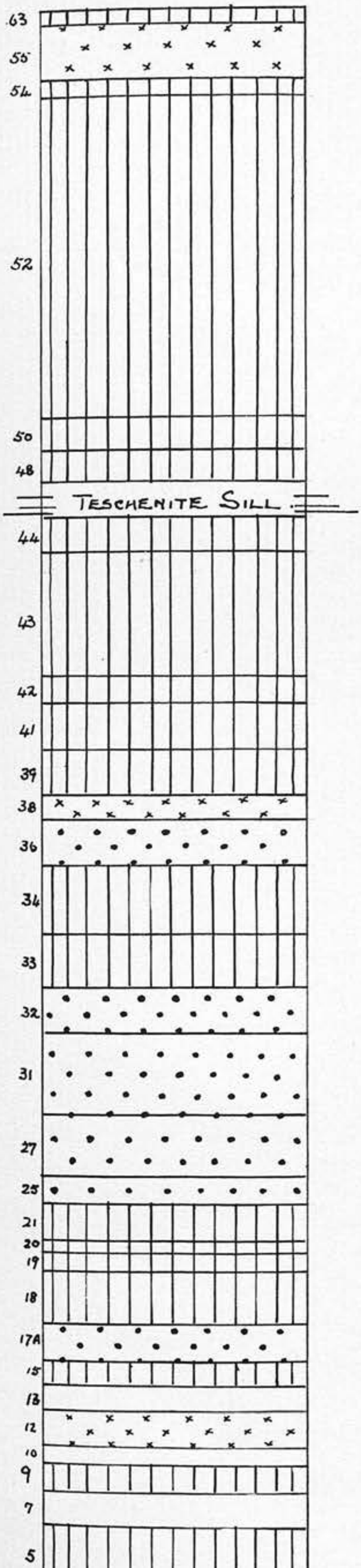
Beyond this horizon, which is taken as the base of the Carboniferous Limestone Series, is a succession of sandstones, shales, fireclays, coals and limestones. Near the old breakwater at Tyrie is a quartz dolerite sill. (See also page 91 of this paper).

ZONES.

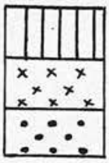
A consideration of the sequence of the lava-flows suggests that a system of zoning might be applied. The earliest members are basalts of a coarse Dalmeny type, followed by one of the Hillhouse variety. The succeeding five flows belong to the coarse Dalmeny type, for the single Kinghorn basalt (No. 17A) thins out rapidly to the north and can be overlooked for the present purpose of establishing a series of belts on the map. Next comes a suite of four/

four members, all basalts of the Kinghorn type, and these are succeeded by seven Dalmeny basalts associated with one of the Kinghorn and one of the Hillhouse variety. Beyond Kinghorn Bay the lava-flows are rather badly weathered but they can be identified as members of the Dalmeny group, and the sequence is thereafter closed by a Hillhouse basalt followed by an exceedingly felspathic Dalmeny one. Detailed mapping has shown that on broad lines the zones established for the coast section also hold good for the inland exposures.

TABULAR REPRESENTATION of LAVA-FLOWS of the COAST SECTION.



KEY.



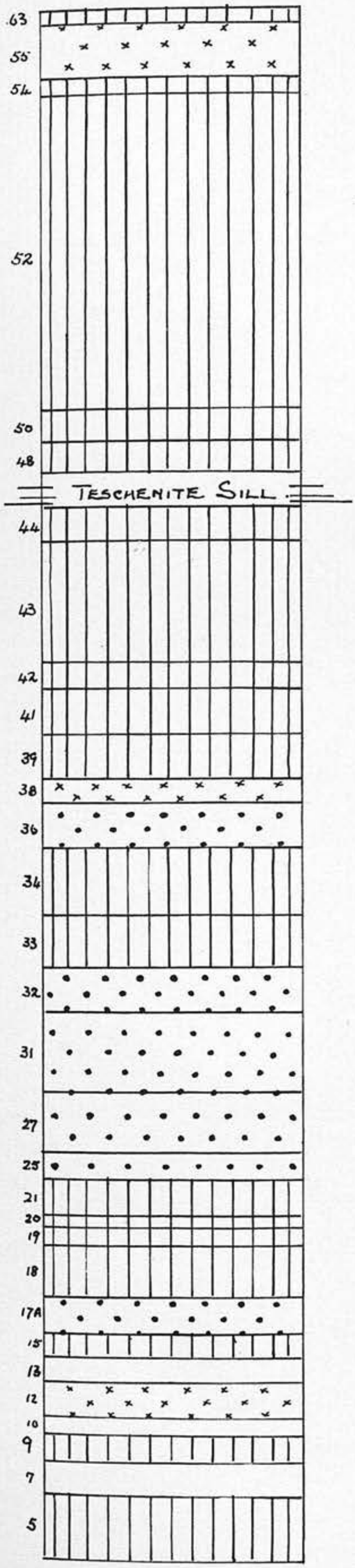
BASALT OF THE DALMENY TYPE.
BASALT OF THE HILLHOUSE TYPE.
BASALT OF THE KINGHORN TYPE.

NOTE. THE UNSHADED PORTIONS OF THE COLUMN REPRESENT UNCLASSIFIED VESICULAR BASALTS.

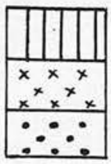
Vertical Scale

1 in. = 100 feet.

TABULAR REPRESENTATION of LAVA-FLOWS of the COAST SECTION.



KEY.



BASALT OF THE DALMENY TYPE.

BASALT OF THE HILLHOUSE TYPE.

BASALT OF THE KINGHORN TYPE.

NOTE. THE UNSHADED PORTIONS OF THE COLUMN REPRESENT UNCLASSIFIED VESICULAR BASALTS.

Vertical Scale

1 in. = 100 feet.

INTRUSIONS.

As was indicated in the introduction to that section of this paper which deals with the lava-flows, the discrimination between effusive and intrusive igneous rocks is by no means easy. In many cases the interpretation of outcrops had to be based on petrographic relationships of the rock to the nearest igneous mass whose junction with the adjacent sediments was clear.

One of the results of this investigation has been to show that the intrusions are developed in broad geographical zones, and accordingly they will be described in a similar manner. Below the Burdiehouse Limestone are a number of sills of doleritic and teschenitic characters, while on that horizon is a persistent development of Dalmeny type basalts, most of which have been converted to White Trap. Above the Burdiehouse Limestone there are five belts of intrusions in the order Hillhouse basalts, teschenites, Dalmeny basalts, olivine dolerites and quartz dolerites. The last-named follows/

follows very closely the outcrop of the Hurlet Limestone. The petrographic characters upon which their classification is based will be considered first and their field disposition and variation afterwards.

PETROGRAPHY of the INTRUSIONS.

I. Basalts.

The descriptions of these rocks given in the section dealing with the lava-flows indicate equally well the characteristics of the finer-grained intrusions. (See page 29). As is to be expected, it is in this group that the greatest development of xenocrysts is found. Fragments of quartz surrounded by radiating augite prisms abound in places, large corroded crystals of augite and plagioclase have been noted, and nodular accumulations of olivine up to half-an-inch in diameter are not uncommon.

It is as a differentiation product of these intrusions that a very felspathic basalt is found. (Pitmethven Wood to the north of Aberdour.) This is a/

a rock carrying large serpentinised olivines, together with smaller phenocrysts of pale green augites and tabular felspars. These are set in a groundmass consisting of small laths of labradorite and granular augite, together with cuboid specks of black iron oxide and a little glass. This basalt can best be described as a facsimile of the Lion's Haunch type (12).

In the middle of the Raith mass is a basalt of a type not found elsewhere in the area. (See Fig. 7). It is coarse in texture and unusually rich in porphyritic crystals. The most conspicuous phenocrysts are large tabular felspars - labradorite. Next in order of importance are the augites which are as large as the felspars and are purplish and somewhat pleochroic. Twinning and zoning structures are present, and there is a tendency to glomeroporphyritic aggregation. The olivines are slightly smaller in size and are replaced by iddingsite. The groundmass consists of small laths of felspar which are sub-ophitic towards the pyroxene phenocrysts, a little/

little prismatic augite, and numerous flakes of black iron oxide. Apatite is developed in minute needles and is associated with a little analcite. A few tiny brownish flakes of biotite are present, and there is a slight residue of undifferentiated glass. From this description it is clear that the rock is a coarse basalt of the Dunsapie type. (13)

II. Teschenites.

The teschenites of the area are readily subdivided into two groups, there being seven occurrences of the first type and two of the second.

(a). The first group includes rocks which are strikingly ophitic, large irregular plates of pale green or slightly purplish augite being penetrated by lath-like felspars which are in most cases of small size. The pyroxene shows some zoning but twinning is not very common. There is no marked dispersion. The felspar is in the main labradorite and is often zoned. Serpentinised/

Serpentinised olivines, often approaching idiomorphism, are numerous but of no great size. There are large patches of analcite which may be clear or turbid, and which in some cases show idiomorphic development in druses. (See Fig. 8). Cracks in the analcite are often filled with calcite or zeolites. Clear analcite often occupies the angle between adjacent felspars. There are numerous apatite needles, and these are often in association with the analcite. Irregular growths of ilmenite are common. Zeolites are abundant in many of these rocks, both natrolite and thomsonite being present. (See Figs. 9&10).

Rocks of this type are found at Inchmarton Plantation and Broad Hill near Aberdour, at Rodan Braes behind Burntisland, at Pirniss Plantation, and as the three sills in the coast section north of Kinghorn.

(b). The highest sill in the town of Burntisland belongs to the second type of teschenite which is finer/

finer in texture and more felspathic in character. It is typically sub-ophitic. The small crystals of titanaugite usually show a tendency to idiomorphism and to glomeroporphyritic aggregation. In colour the pyroxene is slightly purplish with markedly purple and pleochroic borders. Zoning and twinning structures are common. There are many large tabular crystals of labradorite with less basic margins, together with irregular patches of untwinned felspar. Small serpentinised olivines with idiomorphic outlines are fairly common. There is much analcite, that replacing the felspars being in general clear, while irregular areas are filled with a turbid variety much penetrated by apatite needles. Tangential biotite is sparingly developed. Ilmenite in skeletal growths is common, and there is a considerable amount of chlorite as a decomposition product. (See Fig. 11).

At the corner of the road above Hallyards/

Hallyards is a thin sill from which road metal has been quarried. The rock is far from fresh but it possesses undoubted affinities with the type of teschenite just described. It is even finer grained than the Burntisland rock, but resembles it in being sub-ophitic. A purple titanaugite is abundantly developed in small prisms which show a strong tendency to idiomorphism. The tabular felspars are in the main labradorite. Smaller laths of the same nature occur interstitially. Small serpentinised olivines are present but not to any great extent. There is much ilmenite. Analcite is present as tiny clear patches associated with some of the felspars but is most strongly developed in irregular patches. These are filled with a turbid material in which idiomorphic augites appear. In some cases calcite replaces the analcite of these areas. The presence of a little mesostasis in this rock shows a divergence from the characters of the normal teschenites, although a similar structure has been found in the teschenite/

teschenite of the Isle of May.[14]

There is one peculiarity which practically all these teschenites have in common. While analcite is found interstitially between the felspars, and also to a certain extent replacing them, there is a striking tendency for this mineral to be developed in irregular areas. Its association with pyroxene and apatite precludes the possibility that the mineral is of secondary origin. It seems reasonable to suppose that the analcite crystallised while the earlier constituents formed a plexus. The view that the analcite is to be regarded as an active chemical agent is supported by the clearly defined salients which that mineral appears to drive into the felspars.

III. Olivine Dolerites.

The olivine dolerites occurring in this area are a somewhat varied assemblage, for although their constituent minerals are/

are almost identical throughout, there is considerable diversity of texture, structure and proportional composition. Of the first element of variation, attributable to differences in cooling, nothing need be said. From the point of view of structure there is a clear line of demarcation between the non-porphyritic strongly ophitic dolerites at Burntisland, and the porphyritic, generally sub-ophitic, members of the Raith suite.

The Burntisland dolerites are a uniform group characterised by the presence of large, usually serpentinised, idiomorphic olivines together with anhedral crystals of pale brownish augite which is practically always devoid of zoning or twinning. The pyroxene is penetrated by tabular felspars of considerable size whose composition is in the main that of labradorite, but an occasional variation in the direction of andesine has been noted. In general the felspar is markedly zoned. The larger crystals are sometimes penetrated by small laths of labradorite more basic in composition than the outer zones/

zones of the surrounding felspar. In certain parts there is a slight tendency towards the development of tiny felspar crystals interstitially. Black iron oxide is the most abundant accessory. (See Fig.12)

The olivine dolerite sill at Colinswell is exceptionally basic in its lower part, where it is composed of a mesh of serpentine in which fragments of pale brown augite are entangled. Strings of black iron oxide occur plentifully throughout the mass. This rock, described as a picrite, has at various times attracted the attention of collectors, both on its own account and on that of the White Trap underlying it.

The dolerites extending from the Raith westwards to Auchtertool are of greater extent and show correspondingly greater variation. They are essentially porphyritic, either in olivine alone or in olivine and augite. The former variety is the more common one, and in its coarsest form has been described as the Galliston type (15) of dolerite.* It consists/

* N.B. There has been a systematic misspelling of this name as Gallaston.

consists of idiomorphic olivines, partially replaced by iddingsite, set in a plexus of lath-like labradorites which usually show zoning. The interstices are occupied by green augite with which the felspar is in sub-ophitic relationship. The pyroxene shows a tendency to idiomorphism, and is often appreciably darker at the rims. Zoning or twinning is rarely seen. A band of tiny augites sometimes surrounds the olivine phenocrysts. Black iron oxide and apatite are the only accessories of note. Towards the lower margin of this intrusion the pyroxene becomes slightly pleochroic and twinning and zoning are developed. No primary analcite has been identified in this rock. (See Fig. 13).

The middle portion of the upper part of the Raith mass is a basalt of the Dunsapie type. In texture it is as coarse as the Galliston type rock, and there seems no reason to doubt that it is an intimate part of the Raith suite. In the absence of sub-ophitic structure it must, however, be termed a basalt, and for that reason its description is given on page 58.

A/

A finer-grained rock with clear relationship to this type was obtained from the long sill which lies between the two main portions of the Raith intrusion.

The upper part of the Raith suite is badly decomposed but it was possible to determine that it consists of a felspar-rich dolerite carrying porphyritic olivine. To the west there is a distinct tendency towards the development of ophitic structure.

IV. Quartz Dolerites.

These rocks have been described so exhaustively in previous investigations and their characters are so uniform throughout, that no further reference to their petrology is necessary. The practically constant presence of iron pyrites or marcasite is as striking a feature of these rocks in South Fife as has been recorded in the case of similar intrusions in East Fife.(16) (See Fig. 14).

Closely related to the quartz dolerites is a/

a non-olivine-bearing dolerite which has been termed by Hatch (17) the Burntisland type from the locality in which it occurs. The rock is coarse in texture and is generally strongly ophitic. There are large tabular felspars showing extraordinarily well-defined zoning, the banding varying from basic labradorite to near oligoclase. Multiple twinning is general but there are some irregular patches which are untwinned but with equally pronounced zoning. (Fig.15). Networks of small felspar laths occur in places and fill in the interstices between the major constituents, in many cases penetrating the larger felspars. They have a higher refractive index than the zones they traverse. The remainder of the rock is very largely a pale brownish augite, devoid of crystalline shape, zoning or twinning. Iron oxide is present in large irregular flakes, usually black but some patches show a yellowish tint in reflected light, so that pyrites is probably present as well as magnetite and ilmenite. Even in the coarsest parts of this rock there can be seen some interstitial mesostasis. A few very small patches of quartz have been identified in one or two sections./

sections. It may be of secondary origin.

The two lower sills at Burntisland yield examples of this non-olivine-bearing dolerite, and the Black Rock is of similar composition although in certain parts it includes small augites showing twinning and a tendency to idiomorphism, as well as the pyroxene described in the last paragraph.

FIELD CHARACTERS and DISPOSITION of the INTRUSIONS.

I. Intrusions Below the Burdiehouse Limestone Horizon. -

Olivine-free Dolerites - The lowest sill exposed at Burntisland extends from the docks eastward to the Lammerlaws, and what is presumed to be a continuation of it is found at the Black Rocks, half-a-mile distant in a direction slightly south of east. Its thickness is unknown as the base is lost at sea-level, but it is significant that the rock there is still remarkably coarse. Spheroidal weathering is strikingly developed and to such an extent/

extent that it is difficult to obtain fresh material. This rock has been classified by Dr Hatch as an <u>olivine-free dolerite</u>, but it has strong affinities with the <u>quartz dolerites</u>.(17)

The middle sill passes through the centre of Burntisland, forming a marked feature from Rossend Point on the west to the Erskine U. F. Church on the east, where it apparently dies out. At Rossend Point both the underlying and overlying sediments are exposed, and their induration can be observed. Petrographically this rock is very similar to that at the Lammerlaws.

<u>Teschenite</u>. - The upper sill at Burntisland forms a steep ridge of no great size running parallel to the lower sills, and extending from the British Aluminium Company's Works to Greenmount House. This intrusion is a <u>teschenite</u>.

<u>Olivine Dolerites</u>. - To the west of Burntisland a sill can be traced from Colinswell to Carron Harbour. Below it are sandstones and shales, the latter being responsible for a narrow band of White Trap/

White Trap at the contact. The rock above is dark in colour and full of olivine, and has been termed a picrite, but its character is really that of an olivine dolerite with a very basic lower zone. A finer-grained part, presumably near the top of the intrusion, is seen near the bridge over the railway.

Higher up, in the sides of the tram-line to the Nine Lums mine at Bendameer, another sill is exposed, the rock being again an olivine dolerite although it has been replaced to such an extent by carbonates as to be almost unrecognisable in hand-specimen.

To the east of Burntisland, in a cliff below Dodhead Golfcourse is exposed an admirable section of a sill. In its main part it follows the bedding-planes, but off-shoots are clearly visible transgressing the sediments, especially towards the top where the country rock has been lifted up and a series of "wedges" of igneous material have been driven at different horizons into the surrounding strata. Contact alteration has occurred to degrees of intensity varying from mere induration of sediments/

sediments to the production of hornfels which are sometimes spotted, and hard quartzites. Much movement has taken place at the time of injection as the surrounding sediments show marked dislocation and pronounced folding. The rock is a coarse <u>olivine dolerite</u>.

Along the L. and N. E. R. line about a mile to the east of Aberdour, there is exposed an intrusive <u>White Trap breccia</u> which is described along with similar rocks in the next section.

II. <u>Intrusions on the Burdiehouse Limestone Horizon</u>.-

<u>Dalmeny Basalts and White Traps</u>. - Owing to the commercial value of this limestone it is exposed in several quarries, and in them it can be shown that the intrusions about this horizon have characteristic features of their own. Where igneous material has penetrated the shales and limestone there is a development of the rock known as White Trap. Veins of this nature can be seen in the quarries at Dodhead, East Brosyhall, East Grange and Kilmundy./

Kilmundy. They are fairly soft rocks with a cream colour and a considerable assemblage of calcite amygdules. Subsequent fracturing is by no means uncommon, and "dykes" of calcite remain as evidence. The intrusive nature of the veins of White Trap is well shown by their ramification and by the hornfelsing they produce along their line of contact with the sediments. The intrusions were apparently of the nature of basalts of the Dalmeny type, with a slight tendency towards the development of microporphyritic felspar, and less-altered members of the suite are exposed at Whinnyhall Hillock, and at one of the Knolls to the west of Binnend. It is significant that these appear at horizons somewhat above the Burdiehouse Limestone. A normal basalt of the Dalmeny type of presumably the same suite is exposed at Newbigging immediately above the limestone. At its eastern extremity it also passes into a White Trap. Four of these exposures call for more detailed consideration.

In east Brosyhall Quarry is exposed the Burdiehouse/

Burdiehouse Limestone together with the adjacent shales and sandstones. The continuity of these sediments is disturbed in the northwest corner for a distance of about thirty feet. There an extraordinary mixture of "brecciated" White Trap together with included fragments of the country rocks is revealed. Veins of intrusive material penetrate the undisturbed rocks to the west, but the junction to the east is obscured by a turf slope beyond which the sediments reappear following their normal course. In this brecciated area the apparent development of White Trap in irregular spots is deceptive, for it really forms the binding material and sends tongues into the detached fragments of the country rock. In shale there is a flow-like structure of the igneous material throughout the mass. In sandstone the White Trap seems to have advanced in fairly even semi-circular salients, while in limestone there is a marked "frilling" of the junction. The White Trap is thus intrusive as regards both the country rock and the boulders within its own mass. The sediments to/

to the east of this exposure have been subjected to pressure and movement. For a space of eight yards the heavy sandstones have been pushed over thin limestones and shales, accompanied by faulting and overthrusting on a small scale. To the west, the limestone is exposed in a small subsidiary quarry, and there also some evidence of dislocation can be seen.

An even more interesting exposure is seen at Whinnyhall Hillock, this time on the horizon of the Binny Sandstone. At the east end of the steep ridge vegetation obscures the ground, but loose fragments indicate the presence of sandstone. The first outcrop is a gray-blue basalt, which becomes increasingly vesicular as it is traced westwards. The cavities are of large size and are in general filled with calcite. This passes rapidly into a brecciated zone where large angular pieces of basalt are set in a matrix of very fine-grained tuffaceous material. Beyond this is exposed a mass of White Trap associated with fragments of country rock in a manner similar to that described in the case of the Brosyhall/

Brosyhall intrusion. A disused quarry truncates the exposure here, but there is no evidence of any westward continuation. From end to end this peculiar outcrop cannot measure more than one-hundred-and-fifty yards. Under the microscope the basalt of this intrusion is seen to be partially replaced by carbonates, only the felspars being unaltered. In the brecciated portion there is an assemblage of angular fragments of this rock, which show no signs of chilled margins, together with smaller pieces of another basalt and some volcanic ash. The binding material of the breccia is a very fine-grained ash.

The third example of the disruptive nature of a White Trap intrusion is to be seen at the west end of Kilmundy Quarry, where the igneous material truncates and plicates the sediments to the east. Fragments of limestone and shale are scattered throughout the intrusion, the latter rock being riddled with veins and tongues of White Trap. To the south-west the sediments are in stronger force but even to the limits of the exposure are exceedingly shattered. At the north-west margin the steep/

steep rise of the intrusion through the sediments is well exposed, and at various parts of the junction are hornfelsed shales.

As was mentioned in the previous section, there is an intrusion revealed on the side of the railway line between Aberdour and Burntisland. While this is considerably below the Burdiehouse Limestone horizon,its characters and relationships place it rather with the suite just described. Along the line to the west of the smaller neck there appears a curious deposit partly grayish, partly reddish, and with evidence of brecciation in places. The clue to its identity is indicated by the presence of several fragments of shale. This feature is much more strikingly developed higher up,where the matrix is a cream-coloured White Trap in which are scattered fragments of shale in all stages of absorption. Apart from the outlines of a few scattered olivines, the rock is devoid of the usual mineral structures, but there is strong evidence of fluxion. There is a strong development of dolomite in/

in tiny rhombs. A considerable quantity of angular quartz grains have been caught up, a feature quite in keeping with the dyke-like rise of the intrusion through the adjacent arenaceous sediments.

In the field these intrusions are characterised by short lateral extent, their sides being nearly vertical, and from the main part there are off-shoots which penetrate the surrounding strata. That the rise of this mass was accompanied by considerable force is indicated by the intense brecciation of the country rock, many shattered fragments of which are incorporated in the intrusion and are themselves penetrated by tongues of igneous material. In the cases examined the intrusion is of the nature of a Dalmeny basalt which has been converted by contact with shales into a White Trap, but in the tongues penetrating the boulders and fragments there is practically no trace of mineral structure with the exception of an occasional ghost of an olivine. This may readily be interpreted as being due to chilling. There still remains to be considered the source of the power which forced the intrusion/

intrusion to assume a vertical direction, and which dislocated the surrounding strata so markedly. One possible explanation is suggested by the Whinnyhall exposure where the intrusion can be seen in several aspects. The striking characteristic of the rock is its strongly vesicular structure. In three of the four occurrences of this nature the intrusion is associated with the Burdiehouse Limestone, while the Aberdour White Trap cuts a lower calcareous bed, and it is possible that the hot magma was able to drive off a considerable quantity of carbon dioxide from fragments of these rocks. In this way the vesicularity of the basalt may be explained, while the uprise of gas bubbles through the igneous material would, according to Daly (18), greatly increase its activity. Cooling would produce a cone-like mass of basalt at the top of the intrusion and at the same time permit the carbon dioxide to attack the silicates with the formation of White Trap. At lower levels the still molten magma would continue to generate carbon dioxide, the accumulation of which below the White Trap cap might well reach a stage where/

where an explosive shattering of its confines would result. Further brecciation would occur when the core of the intrusion cooled and in its turn was converted to White Trap, for that process is accompanied by an increase in volume of from five to ten per cent. This could only be achieved by fracture of the earlier formed White Trap walls and roof of the intrusion.

This type of phenomenon was first discovered and described by T. C. Day (19) in his investigation of the district around Cheese Bay, Gullane. He noted the intrusive nature of the junctions between White Trap and incorporated boulders as well as the surrounding sediments, and termed them "intrusion breccias". The presence of thrusts near the top of the dome-shaped igneous masses, their constant association with dolomitic sediments, and the vesicular structure developed in their neighbourhood, were demonstrated in several places.

III. Intrusions Above the Burdiehouse Limestone.

III. Intrusions Above the Burdiehouse Limestone.

Under this heading must be described the remainder of the intrusions as far as the Hurlet Limestone horizon which represents the upper limits of the field of this investigation. The rocks of this suite are olivine basalts, teschenites, olivine dolerites and quartz dolerites, and these are developed as a series of zones encompassing the lava-flows to the west, north and north-east.

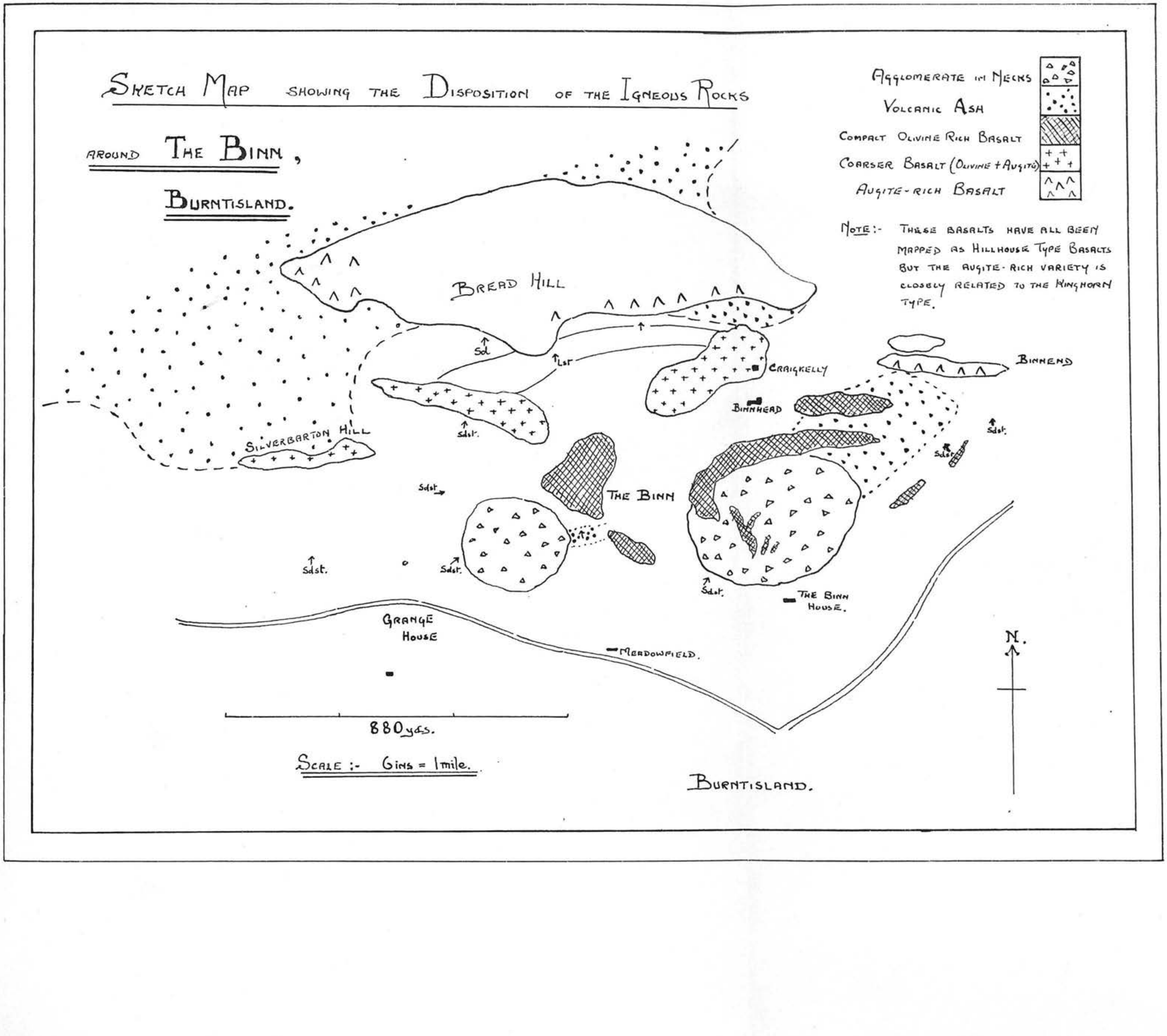
(a). First Basalt Zone.-

As is shown on the appended map of the area, the south-western portion lying behind the towns of Burntisland and Aberdour is characterised by a considerable number of irregular outcrops of igneous rocks. Such of these as appear to have some connection with the necks of the area have already received mention under that head. No useful purpose can be served by enumerating all the exposures, but they have been subjected to microscopic investigation, their macroscopic characters being too similar in most cases to yield any results.

The/

The intrusions around the Binn are of interest in that they comprise a compact group of exposures whose petrological modifications are identical with those of the rocks disposed round the western periphery of this particular zone. The rocks concerned are essentially fine-grained olivine basalts greatly resembling many of the lava-flows.

To the south, along the scarp of the Binn, are several intrusions in the form of both dykes and sills, the rocks being basalts of the Hillhouse type, rich in olivine, which is the sole porphyritic constituent. To the north of these there is a belt from Craigkelly Farmhouse to Silverbarton Hill, broken in parts but quite continuous petrologically, composed of a coarser basalt, which for want of a proper name must still be termed Hillhouse in that augite is the conspicuous component of the groundmass and is also slightly represented porphyritically. Behind this is the large mass of Bread Hill which constitutes a third belt. Here the rock carries a considerable amount of augite as a porphyritic/


Sketch Map showing the Disposition of the Igneous Rocks
around The Binn,
Burntisland.
Agglomerate in Necks
Volcanic Ash
Compact Olivine Rich Basalt
Coarser Basalt (Olivine + Augite)
Augite-rich Basalt
Note:- These basalts have all been mapped as Hillhouse Type Basalts but the augite-rich variety is closely related to the Kinghorn type.
Bread Hill
Sd
Lst
Sdst.
Silverbarton Hill
Craigkelly
Binnhead
Binnend
The Binn
Sdst
Sdst.
The Binn House.
Grange House
Meadowfield.
880 yds.
Scale :- 6ins = 1mile.
Burntisland.
N.

porphyritic constituent. Towards the extremities of the mass the rock becomes richer in augite phenocrysts, especially in the west where the pyroxene exceeds the olivine both in size and numbers. The corresponding eastern portion has not quite so strong a development of augite and approaches the rock of the middle belt in composition and texture.

The field evidence suggests that these intrusions are in the main a suite of sills, for sediments are seen at several places on the steep south-facing scarps, and at Silverbarton the Binny Sandstone, carried on the back of the rock of the middle belt, is transformed into a quartzite. Petrologically, the entire group may have come from one parent magma, so strong are the resemblances between the individual members. Their differences are in the main confined to the porphyritic constituents — to those crystals which indicate the mineral present to excess in the magma. On this assumption, olivine was the preponderating constituent at the lower levels, while about the middle there was early crystallisation of both olivine/

olivine and augite. Near the top, the porphyritic augite content is as great as, if not greater than, the olivine. This is suggestive of gravitational differentiation.

To the west, the towering mass of Dunearn Hill is mainly composed of a columnar basalt whose characters associate it with the third or highest belt behind the Binn. Along the rising ground from Torry Hill to Dalachy further outcrops of a similar nature occur. Reference has already been made to the dykes in the two smaller necks at Balram, which lies to the north of this area. (See page 20). The fine-grained basalt constituting them has obvious affinities with those under consideration.

(b). Teschenite Zone.

Beyond the area just described, the character of the intrusions undergoes a change, the rocks there being teschenitic in character. Dr F. Walker has already described[20] the occurrence of two teschenite sills at Aberdour. To the north of these/

these, but separated from them by an east-west fault, there is another outcrop, somewhat different in certain respects but nevertheless a teschenite, which constitutes the rising ground from Humbie to Inchmarton. From Croftgary to Broad Hill there is a long ridge of similar composition. It is rather curious that the steep scarp face is to the north-west, in the direction of the dip of the surrounding sediments, but the topography is here complicated by the presence of a deep gully possibly of glacial origin.

Continuing in the direction of the general strike of the beds, the next outcrop of teschenite is at Pirniss Plantation, a narrow east-west ridge lying along the northern limits of the mass of Hillhouse basalt-flows. A similar rock appears about the same horizon at the east side of Kinghorn Bay, and has already been mentioned as No 46 of the coast section. (See page 49). A very small exposure of teschenite has been located in the middle of a field above Rodan Braes, where it is apparently intruded immediately above the preliminary effusions of/

of Dalmeny type basalts.

On the western side of the anticline no further appearance of teschenite has been noted until the extreme north-west limits of the area are reached. Where the road rises steeply beyond Hallyards there is a thin sill of a teschenitic character lying between two olivine dolerites. To the east, however, there is a stronger development of rocks of this nature, two sills being exposed along the shore south of Kirkcaldy. (Nos.65 and 69A of the section described on page 52 .)

(c). Second Basalt Zone.

To the north-west of the district there is an irregularly-shaped area of igneous rock stretching from the north of Balram to beyond Auchtertool, and elongated in a N.E.- S.W. direction. The rock is a basalt of the Dalmeny type, and is so similar to that of the lava-flows that it might well represent a continuation of that suite. It must be admitted that a comparison between the Auchtertool mass and the lavas occupying the appropriate horizon shows a greater degree of resemblance than of variation. While/

While no clear junctions are exposed, the general outline of the mass indicates strong transgression. (See appended map). Microscopic investigation has revealed the fact that there is a well-developed differentiation throughout. The lower portions are rich in olivine, or olivine and augite. The middle likewise contains many phenocrysts of these two minerals, while the top is extraordinarily rich in felspar. (See page 57). In the case of narrow apophyses and demonstrably rapidly cooled areas, the rock is olivine-rich. Textural variation is in accordance with the hypothesis that the mass is one large irregular intrusion. The outlying portions and the highest ones are fine-grained, while those towards the middle and the east are coarser.

The Olivine Dolerite Zone.

To the north of the lava-flows is an area characterised by the presence of a number of intrusions which are largely olivine dolerites. Their greatest thickness is developed in the region of/

of Raith Park, and although outcrops are rather scanty it is nevertheless permissible to assume that the prominent hill-feature there seen indicates in a general way the superficial extent of these intrusions. From the Raith a number of elongated ridges can be traced westwards to Auchtertool and Camilla Loch, and in an earlier survey certain of these were mapped as lava-flows, possibly on account of the vesicularity occasionally displayed. As the most promising example on being traced to Auchtertool exhibited transgression and contact metamorphism, less clear exposures had to be judged on their petrographic relationships to the intrusive mass as a whole. The complete elimination of lava-flows from this area is the result, but it must be admitted that the southern boundary of the intrusions is to some extent conjectural.

There can be no doubt that the intrusions came from the same magma as the lava-flows as their mineral constituents are, except for some minor details, identical in each case. One feature of the intrusions/

intrusions is their strong development of felspar indicated by felspathic groundmasses, microphenocrysts of felspar, and in one zone large phenocrysts of that mineral. It has already been stated that the later lava-flows showed a tendency to be fairly rich in felspar, and while this peculiarity is of value as evidence of the continuity of differentiation in the parent magma it increases the difficulty of discriminating between the latest lavas and the adjacent intrusions.

Excluding certain small outcrops, the main lower part of the dolerite suite stretches from the west end of Raith Lake to within a short distance of Auchtertool. In the heart of this mass is Galliston Quarry from which the type rock has been described. It is a coarse, olivine-rich, sub-ophitic dolerite. Near the extremities of the intrusion and in the neighbouring apophyses the rock is finer in texture and carries some augite as well as olivine as the porphyritic constituent.

Turning/

Turning to the Raith Hill, which constitutes the main upper portion of the intrusion, it can be divided readily into three zones. At the bottom the rock is an olivine dolerite with a felspathic groundmass. In the middle, augite occurs to a greater extent than olivine as the porphyritic constituent, but the striking feature of this zone is the number and size of the felspar phenocrysts, the rock being a basalt of the Dunsapie type. The highest part of the intrusion is again an olivine-rich dolerite, carrying porphyritic olivine and augite and characterised by a fairly felspathic groundmass.

The western extension of this belt forms some of the eminences round Camilla Loch. None of the material available from that area was in a good state of preservation, but enough of the characters remained to indicate that the rock was an ophitic olivine dolerite. A teschenite sill is associated with these outcrops but it shows considerable differences in character. (See page 86).

From the foregoing description it is seen that again there is a definite differentiation of the material/

material of an intrusion into a lower zone rich in ferromagnesian minerals and an upper one in which felspar is well developed. A more average composition, associated with a finer texture, characterises the more rapidly cooled external portions, and in this connection it is interesting to note that certain of the chilled areas yield basalts of the Dalmeny type indistinguishable from those of the lava-flows to the south.

The Quartz Dolerite Zone.

Outside this area, and constituting a great semi-circular boundary round it, is a belt of quartz dolerites. At its eastern extremity a thin sill above the Hosie Limestones is responsible for the reef immediately to the south of Tyrie breakwater. This intrusion thickens to the north where it is truncated by an east-west fault passing through Raith Lake. This fault displaces the sill about half-a-mile to the east where it can be located at Abbotshall, and from there to Sauchenbush the thickening is rapid. During/

During this part of its course the dolerite lies just above the Hurlet Limestone. Beyond this point there is a curious deep gully which suggests a fault feature. The mapping of the Hurlet Limestone seems to preclude this and either excessive river erosion or an original irregularity in the intrusion may be the explanation. There is a small east-west fault to the north and beyond it the quartz dolerite swings round first to the north and then to the north-west, this time keeping below the Hurlet Limestone. It constitutes the ridge at Torbain and Bankhead and then swells out into the mass at Knockbathy Hill, to the east of which good examples of transgression, thrusting and plication can be seen.

There is a slight break in the continuity of the belt at this point, but beyond Camilla Loch the quartz dolerite reappears and can be traced along the Pilkham Hills to Beverkae Dairy Farm. (Stewart Arms Inn, on old maps.) To the south of this, in the cutting through which the main road passes, contacts can be seen. The intrusion runs in a southerly direction/

direction through Cullaloe Woods, its thickness continually diminishing until it is lost against an east-west fault about two miles west of Aberdour. The area described in this investigation is thus enclosed by a practically continuous belt of quartz dolerites whose extent from end to end amounts to fully twelve miles.

XENOLITH ASSEMBLAGE in STRATUM No. 43.

Reference was made on page 49 to the occurrence in stratum No. 43 of the coast sequence of a curious assemblage of pebbles of foreign material. (21) These appear along a well-defined horizontal zone near the top of the lava-flow. From a maximum thickness of about ten feet below the north end of Kinghorn Battery it rapidly diminishes both to the north and to the south, where it entirely disappears before Carlinhead Rocks are reached. The pebbles consist of/

of quartzite, jasper, chalcedony and hard sandstone. While most of the fragments have an irregular or angular shape, a few show rounded outlines. In the majority of cases the pebbles measure only two or three inches across, but a few have diameters of eight or ten inches.

These pebbles have so restricted an extent that it is difficult to believe that they floated loose up the throat of a volcano and drifted with the lava current to their present position. It seems more likely that a mass of conglomerate, wrenched from its place and transported bodily to the surface, dissociated into its component parts by the combined action of the movement and corrosive powers of the hot lava. The possibility of such flotation in the basalt depends entirely upon the relative densities of the pebbles or their parent conglomerate and that of the molten rock. The specific gravities of the pebbles vary from 2.60 to 2.66 while that of the solid basalt is 2.88. According to F. W. Clarke (22) and A. Harker, (23) both of whom quote Fleischer, (24) there is an increase of density when a solid rock becomes/

becomes molten. R. A. Daly (31) takes the contrary view and gives a series of figures in support of his attitude. Even so, he admits the likelihood of xenoliths floating on a molten basic rock, provided it is not vesicular to any great extent. He gives the density of a molten compact basalt as 2.75, a figure quite in keeping with the contention that the foreign material in stratum No. 43 floated on or within the lava stream. While an Old Red Sandstone age has been suggested for this conglomerate, it may well have come from the Lower Carboniferous.

COMPARISON with VULCANICITY of ADJACENT DISTRICTS.

In East Fife there is a numerous assemblage of volcanic necks with which are associated intrusions. (25) In no case, however, has it been shown that lava-flows issued from these vents. Much of the material of the agglomerates resembles that of the intrusions in being exceedingly basic rocks of the limburgite or monchiquite type. Felspar, except in the case of certain parts of the Chapel Ness intrusion, is practically absent, while capricious occurrences/

occurrences of nepheline have been noted.[26] From a consideration of their relationships to the tectonics of the surrounding country, Sir Archibald Geikie believed these necks to be of Permian age. There is one exposure, in Aithernie Den near Leven, where a sheet of basalt lying among tuffs suggests a lava-flow, and its horizon is between the Index Limestone and the Gair Limestone.[27]

Lavas and tuffs were produced in East Lothian in Calciferous Sandstone times, the commencement of volcanic activity being probably not long after the Burdiehouse Limestone was laid down, although that horizon cannot be definitely determined owing to lack of palaeontological evidence. The products of this activity were a lower suite comprising limburgites, basalts carrying porphyritic felspar, and mugearites, and an upper one with trachytes.[28] Among the basalts the Dunsapie, Craiglockhart and Markle types are represented, and their order of effusion indicates a general trend in the direction of diminishing basicity. After the out-pouring/

out-pouring of the basalts a series of sills were developed resembling them in character but less conspicuously porphyritic in structure. The trachytes which followed the basalt-flows were partly effusive and partly intrusive. The later intrusions in this district include analcite basalts, essexites, phonolites, and teschenites. The rocks of the East Lothian suite are thus characterised by considerable diversity of structure and composition.

In Midlothian the first indications of igneous activity are found on the Arthur Seat volcanic horizon, immediately above the cementstones.[29] The lava-flows there are basalts of the Craiglockhart, Dunsapie, Markle and Dalmeny types together with mugearites. Associated with these are several intrusions of a similar nature, and a teschenite sill. The lava-flow at Dalmeny village, from which the type basalt of that name was obtained, occupies a higher position in the sequence, lying between the Broxburn Shale and the Fells Shale. Tuffs have been found at other horizons.

The/.

The Bathgate Hills volcanic sequence was worked out by Dr. J. D. Falconer (30) who found that the Houston Coal was followed by the Houston Shales and Marls, together with some thin sandstones, before igneous activity commenced. The first volcanic zone comprises interbedded sandstones, shales and tuffs. Above this is a belt of fine-grained olivine basalts associated with some thin bands of sediments, and succeeded by coarser-grained "dolerites" and another group of compact basalts. The Tartraven Limestone marks the upper limits of this zone, and a further out-pouring of olivine basalts and "dolerites" occurred. The Hurlet Limestone appears immediately above and marks the termination of the Calciferous Sandstone Series. Between this horizon and the Index Limestone is another group of lavas of a similar nature. A final emission of limburgites and "dolerites" followed and this phase of igneous activity terminated with the deposition of the Castlecary Limestone. These lava-flows were classified on petrological grounds into four main groups corresponding to the Galliston/

Galliston, Dalmeny, Hillhouse, and limburgite or Kinghorn types. A suite of intrusions corresponding closely with these rocks was also recorded and these were regarded as more or less contemporaneous, while a group of augite dolerites was considered to be of much later date.

In the Burntisland district there are several beds of volcanic ash below the Burdiehouse Limestone, but the first lava-flows did not occur until shortly after the deposition of the Houston Coal. This phase terminated before the Second Abden Limestone was laid down, so that it belongs entirely to the Oil Shale Group. The flows show no very great variation in composition, being basalts of the Dalmeny, Hillhouse and Kinghorn types. Associated with these lavas is a suite of intrusions of Dalmeny and Hillhouse types of basalt. Finally there is a strong development of coarser grained intrusions of the nature of teschenites, olivine dolerites and quartz dolerites.

From the foregoing notes it is clear that the/

the Burntisland igneous activity most closely resembles that of the Bathgate Hills. The rocks of the lava-flows and of the associated fine-grained intrusions are identical in composition and structure. The later augite dolerites of the Bathgate area have much in common with the non-olivine-bearing dolerite of the two lower sills at Burntisland. The activity of the two areas was for long contemporaneous, but in Fife it terminated earlier.

CONCLUSION.

The Carboniferous igneous activity in the district around Burntisland is revealed by volcanic necks, lava-flows and intrusions, an association in occurrence which suggests a relationship in activity. Of the seven necks which do not cut horizons higher than the Houston Coal, the Binn is the most important in point of view of size, and is suitably situated with regard to the disposition of the lava-flows for it to be considered the focus of eruption. It is possible that the neighbouring smaller vents at Kilmundy and Dodhead were parasitic to the major feature. The large neck at Aberdour is more distant from the flows and is situated further to the west than any member of the lava sequence. The three necks at Balram appear to have been ash cones and the Kirkcaldy vent may have belonged to the same group. There is a fairly persistent bed of volcanic ash found below the Capledrae Coal in various parts of South Fife, and it may represent the material ejected from these necks. The chronological position of the small/

small pipe at King Alexander's Craig, as was mentioned earlier, is still a matter of some doubt.

The detailed petrographic examination of the basalts of the area has established the fact that they are essentially an olivine, augite, labradorite assemblage, with iron oxide, analcite, chlorites and zeolites as minor constituents. There is no inherent difference between the effusive and the intrusive members of this group, and there seems to be no valid reason to suppose that any great time interval existed between them. The olivine dolerites and Dunsapie type basalt show strong resemblances to the compact basalts in composition, and in many cases yield specimens from rapidly cooled portions which cannot be distinguished from certain members of the lava-flows. The coarser textures of the dolerites implies either greater reserves of heat or less rapid loss of it. The larger the intrusion the more heat would be available, but inspection of the map shows that the Auchtertool mass is of fair extent superficially as compared with the Raith dolerite suite,/

suite, and yet the former is comparatively fine-grained throughout. Rather is the explanation to be sought in the more efficient blanketing of the intrusion, an implication that there existed a deeper covering of sediments. It is for this reason that the Raith dolerites are presumed to have followed the basalt intrusions.

The teschenites bear strong resemblances to the dolerites. Their felspar is similar in composition, and it is possible to match either the brown or the purple pyroxene with the porphyritic augites of the basalts. The presence of analcite does not constitute a difference, it is only the much greater quantity present which gives rise to a variation in nomenclature. In comparing the teschenites of the Burntisland district with those from other areas, the absence of amphibole and the exceedingly scanty development of biotite are striking.

It is not possible to be precise with regard to the quartz dolerites. In South Fife, as elsewhere, these rocks are associated with dolerites and teschenites. It is suggested that the quartz dolerites came after the other intrusions for they are/

are developed peripherally round them for a distance of twelve miles. At one place only, in the vicinity of Camilla Loch, is the continuity of this belt broken, and through the gap can be traced the western extension of the Raith dolerite suite. As the quartz dolerite immediately to the north shows expansion in superficial area together with a finer texture than usual, it seems reasonable to assume that the olivine dolerites were developed first. The quartz dolerite magma rising through the beds at a later date, met this obstruction, was chilled against it, and so broke the continuity of its extension. It is impossible, within the area investigated, to fix an upper limit in time for the quartz dolerites, but, having due regard for the agility generally displayed by them in the matter of violent transgression, it is difficult to believe that they would have been developed so evenly round the apex of the Pentland anticline had it been formed prior to their appearance.

Finally it has been noted that in the case of/

of the larger intrusive masses there has been differentiation into a lower zone rich in olivine, a middle one in which both olivine and augite are strongly developed, and an upper one characterised by abundant felspar. This arrangement is highly suggestive of gravitational differentiation.

SUMMARY.

As a result of this investigation, the following points are considered to be established and to represent an advance in the knowledge of the igneous geology of the area.

Necks. Eleven previously known necks have been systematically described and a new one located to the east of Aberdour. From the boulders found in the agglomerate of these necks no evidence has been found that any of them are younger than the Lower Carboniferous. From its inclination to the adjacent lava-flows the pipe at King Alexander's Craig may be of later date than the others.

Lava-flows. Earlier generalised descriptions and some scattered petrographical notes have been replaced by a detailed examination. The rocks have been identified as basalts of the Dalmeny and Hillhouse types. A third variety has been located and described under the/

the name "basalt of the Kinghorn Type".

The result of this classification of the rocks of the lava-flows on the coast section has been to establish a series of zones on broad lines, and this has been applied to the inland exposures with success. In the variation of the lavas there is a tendency towards decreasing basicity in the later members. Analcite has been determined as a fairly constant minor accessory. Two of the outcrops on the coast south of Seafield previously regarded as lava-flows have been remapped as intrusions, and a similar alteration has been made in the case of several of the exposures in the Raith Mass as well as the long ridge of Pirniss Plantation.

Intrusions. The nature of these rocks has been determined by petrographic examination for the first time. They include basalts of the Dalmeny and Hillhouse types, two varieties of teschenites, olivine dolerites, non-olivine-bearing/

non-olivine-bearing dolerites and quartz dolerites. A number of new occurrences have been mapped and several old ones interpreted differently. Throughout the larger intrusive masses there has been differentiation into a lower zone rich in olivine, a middle zone with both olivine and augite well represented, and an upper strongly felspathic zone.

From their arrangement in the field, the order which the intrusions followed seems to have been basalts first, then dolerites, and finally quartz dolerites. It is suggested that the time of their development may have been confined within the limits of the Carboniferous period.

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MICROPHOTOGRAPHS.

Explanation of Microphotographs.

Figure 1. Basalt of the Hillhouse Type.

(Orrock Hill, Burntisland). Small phenocrysts of olivine scattered throughout a fine-grained groundmass of laths of labradorite and granular augite. A large skeletal crystal of olivine is shown.

Ordinary light. x 25.

Figure 2. Basalt of the Kinghorn Type.

(Stratum No 36 of the coast section.) The "synneusis structure" of Vogt is unusually well seen in the development of augite phenocrysts in streams. The polysomatic nature of the core of the crystals is in marked contrast with the continuous practically euhedral rim.

Ordinary light. x 25.

Figure 3. Basalt of the Kinghorn Type.

(Stratum No 17A of the coast section.) The groundmass contains numerous laths of felspar with granular augite and glass, both of which appear black in places in the photograph. In the centre is a fragment of quartz surrounded by glass carrying augite microlites, and an outer zone of granular and prismatic augite.

Ordinary light. x 25.

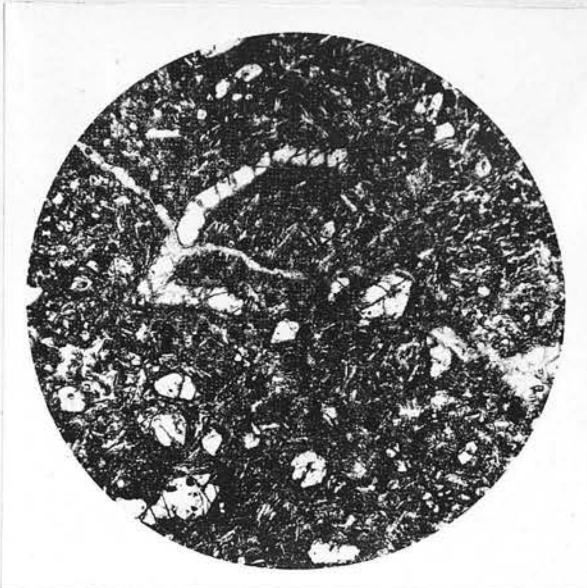

Figure 1.

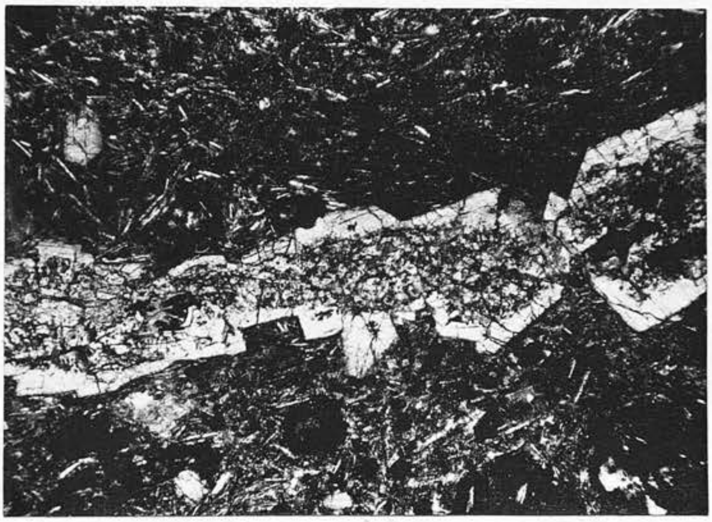

Figure 2.

Figure 3.

Figure 4. Basalt of the coarse Dalmeny Type.

(Stratum No 5 of the coast section. King Alexander's Craig). Large fresh olivine phenocrysts with characteristic cracks and inclusions, set in a groundmass of lath-like labradorite, granular augite, black iron oxide and some analcite. Fluxion structure is developed.

Ordinary light. x 25.

Figure 5. Basalt of the Hillhouse Type.

Dyke intruded into the agglomerate of the east neck of the Binn, Burntisland. Small idiomorphic fresh olivine phenocrysts, showing cracking and corrosion. The dark fine-grained groundmass is mainly composed of granular augite, small felspar laths with some analcite and residual glass.

Ordinary light. x 25.

Figure 6. Basalt of the Kinghorn Type.

(Stratum No 25 of the coast section.) Small phenocrysts of serpentinised olivine and augite set in a fine-grained groundmass of laths of labradorite, granular augite and some residual glass.

Ordinary light. x 25.

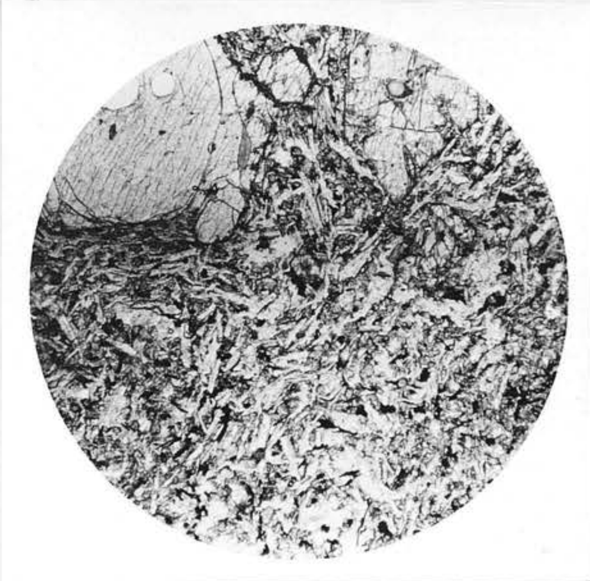

Figure 4.

Figure 5.

Figure 6.

Figure 7. Basalt of the Dunsapie Type.

Lambswell Ridge, Kirkcaldy. Large phenocrysts of augite, labradorite, and serpentinised olivines (black). Between these are small felspar laths some of which penetrate the porphyritic augite. The interstices are occupied by analcite and occasional minute flakes of biotite.

Ordinary light. x 25.

Figure 8. Teschenite.

Pirniss Plantation, Burntisland.

Analcite occupying a cavity. The turbid cubic centre is surrounded by clear analcite showing indication of icositetrahedral outlines.

Ordinary light. x 25.

Figure 9. Teschenite.

(Stratum No 65 of the coast section.)

Irregular plates of augite with which the tabular labradorite is in strong ophitic relationship. The black represents both iron oxide and serpentinised olivines. The turbid patches are analcite.

Ordinary light. x 25.

Figure 7.

Figure 8.

Figure 9.

Figure 10. Teschenite.

Sill south of Seafield Tower.

Large plates of augite penetrated by tabular labradorite. The black areas represent iron oxide and also serpentinised olivine. Clear and turbid patches of analcite are developed throughout, and in association with them are needles of apatite.

Ordinary light. x 25.

Figure 11. Teschenite.

Highest sill at Burntisland. A large tabular labradorite crosses the section. Towards the top left hand side of it is an area of turbid analcite in which are seen needles of apatite in transverse section. A longitudinal section of apatite lies to the right of the felspar. Small prisms of augite are present, together with serpentinised olivine. Some of the light patches are clear analcite.

Ordinary light. x 25.

Figure 12. Olivine Dolerite.

Dodhead, Burntisland. A coarse-grained rock with large anhedral plates of augite with which labradorite is in ophitic relationship. Serpentinised olivines are present but are not of striking size. The black areas are iron oxide.

Ordinary light. x 25.

Figure 10.

Figure 11.

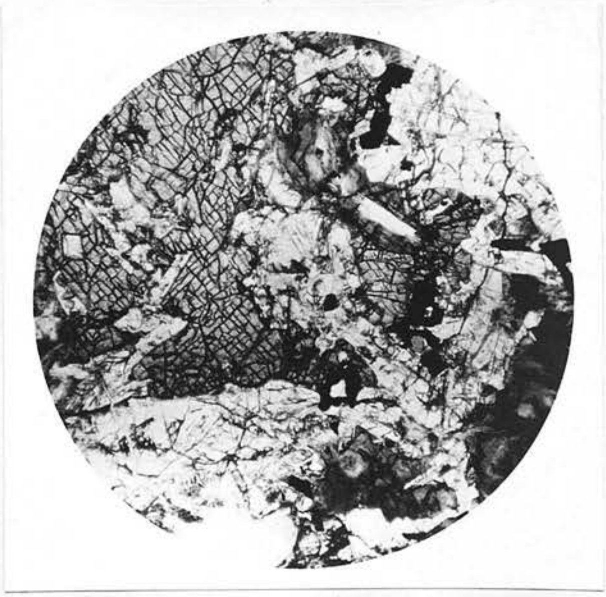

Figure 12.

Figure 13. Dolerite of the Galliston Type.

Galliston Quarry, Kirkcaldy. Large porphyritic fresh olivines with iddingsite developed in cracks and on the margins. The groundmass consists of tabular labradorite which is in sub-ophitic relationship to the small prisms of augite. A little black iron oxide is present. The turbid areas between the felspars are chloritic material.

Ordinary light. x 25.

Figure 14. Quartz Dolerite.

Quarry south of Raith Lake, Kirkcaldy. The decomposed nature of the rock is evident. The tabular felspars are characteristically strongly zoned. Some of the irregular light areas represent the quartz. Of the ferromagnesian content only one fragment of augite remains recognisable.

Crossed Nicols. x 25.

Figure 15. Non-olivine bearing Dolerite.

Lowest sill at Burntisland, Railway Station. The ophitic relationship of the strongly zoned felspars to the pyroxene is well seen. The black portions are partly iron oxide and partly undifferentiated residue.

Crossed Nicols. x 25.

Figure 13.

Figure 14.

Figure 15.

NOTE on the MAP. Place names are given in the letterpress in order to facilitate consultation of maps on the scale of 6" to the mile. It is obviously impossible to indicate more than a bare minimum on the appended map on the scale of 2" to the mile.

One or two minor dislocations of the Burdiehouse Limestone have been omitted.