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Some Observations on the Antrim Basalts and Associated Dolerite Intrusions

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ABSTRACT: The work embodies miscellaneous observations on the general structural characters of the Tertiary basalt lavas and minor intrusions of north-eastern Ireland. Individual lava flows are found to average twenty-two feet in thickness, the thickest reaching 150 feet. Certain flows can be traced horizontally for as much as six miles. Basalt pegmatites are described which bear sodalite, a mineral new to Ireland.

Composite lava flows are recorded for the first time in Ireland. Several examples have been located, and in each the components, separated by a sharp but unchilled contact, are of olivine–basalt and picrite–basalt respectively. The lavas are associated with a swarm of dykes and one, possibly two, dykes are now known to be the feeders of lava flows. Dolerite plugs may also represent the feeders to lava flows.

Six newly discovered plugs are recorded, bringing the total number known to around thirty. The Donegore dyke, formerly regarded as a broad dyke, is re-interpreted as a string of four small plugs.

1. INTRODUCTION

TERTIARY BASALT lavas occupy an area of some 1500 square miles in Antrim and adjacent counties in the north-east of Ireland. Excellent accounts of the general characters of the Antrim Basalts are given by Geikie (1897) and Charlesworth (1935), and a considerable amount of detailed work has been done since then, especially by Tomkeieff & Patterson, as listed in the bibliography, but certain aspects of the Antrim plateau still lack adequate description.

The present work stems from incidental observations made during a regional study of the amygdale-minerals in the lavas, observations on the general structural characters of the lavas and such small-scale features as auto-intrusions. Several composite lava flows, the first to be recorded in Ireland, have been found, and new evidence bearing on the mode of eruption of the basalts includes the discovery of a lava flow connected to its dyke-feeder. In addition to the dykes there are numerous dolerite plugs that have also probably contributed to the lava pile, and during the course of the field work six new plugs have been located and are placed on record for the first time, bringing the total number of plugs known to about thirty.

The volcanic succession consists almost entirely of basalt lavas, although acid rocks occupy a few square miles of country on and around Tardree Hill and in several small patches elsewhere. Detrital beds of any kind are decidedly rare, and bedded pyroclastic rocks are developed on a considerable scale only in the vicinity of the Carrickarede volcano on the north coast of Antrim. Sedimentary beds are practically confined to the interbasaltic horizon, a prominent zone of weathering (Cole, 1912; Eyles, 1952) which over most of Antrim divides the lavas into two series, the Lower Basalts and the Upper Basalts. A threefold succession has recently been established by Patterson (1955a), in the north of Antrim, where there are two such zones of weathering.

The lavas rest upon an eroded surface of Chalk, often with small solution pits and swallow-holes, and there is a thin intervening bed of clay-with-flints, often red and lateritic and occasionally with plant remains at the top of the clay. Cleland (1928, 1930, 1933) has described from Magheramorne and Whitehead a thin bed of redeposited detrital chalk above this clay. Near Donald's Hill the writer has observed silicification of the top of the clay.

It has long been regarded as established that the lavas are the product of subaerial eruptions, from the absence of pillow-lavas and of intercalated marine sediments and marine fossils, and from the presence of occasional plant beds in the succession. The tops of the lava flows are typically red, probably mainly by contemporaneous lateritic weathering. The interbasaltic horizon (Cole, 1912; Eyles, 1952), with its lateritic iron ores and bauxites which have been mined from time to time, is such a zone of weathering of unusual thickness representing a lull of considerable duration between the outpouring of lavas. Detrital (dust) partings of the type described from Iceland by Hawkes (1916) are apparently very seldom developed.

Apart from a group of tholeiite flows developed in the north of Antrim (the Middle Basalts of Patterson, 1955), which attain an aggregate thickness of several hundred feet and include the famous columnar flows of the Giant's Causeway (Tomkeieff, 1940b), virtually the whole of the Antrim Basalts are olivine-basalts (Tomkeieff, 1934) of rather uniform character. They are often rather rich in olivine (20% or more in the mode) and grade into picrite-basalts.

The original thickness of the lava pile is not known. In the Garron Plateau and in places along the western escarpment up to 1000 feet of lavas are exposed for study, but there is no means of telling what thickness has been eroded away. The Aughrimderg borehole in the Coalisland area passed through 990 feet of basalts, and Hartley (1948) estimated that the total thickness of lavas there is about 1600 feet. The Langford Lodge Borehole (Fowler, 1957) passed through 2590 feet of basalts.

The lavas are disposed in the form of a very shallow, boat-like trough with axis pitching towards the south-west, and the base of the lavas attains

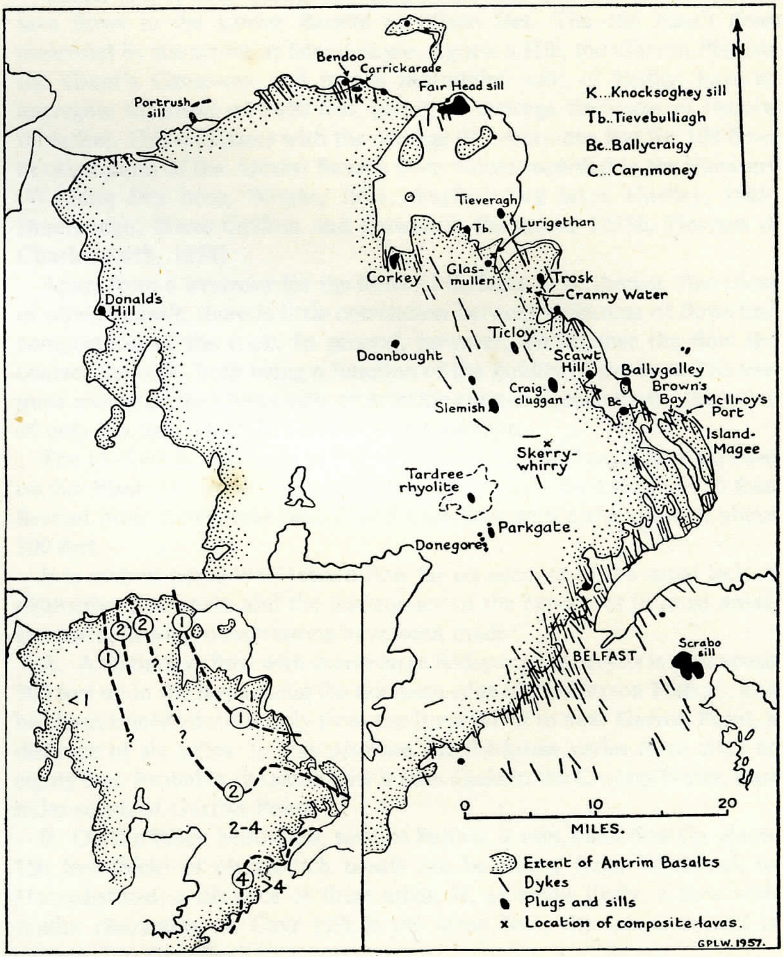

Fig. 1. Sketch-map of the Antrim Basalts showing the distribution of dykes and other intrusions and the location of composite lava flows. Inset map shows tentatively the intensity of the dyke swarm, expressed as percentage stretch

its greatest known depth (2700 feet below sea-level suggested by Hartley, 1948) in the south-west in the Coalisland area. At the other extreme the base of the lavas attains in places an altitude of well over 1000 feet along the prominent escarpments which bound the basalt plateau on the east and west.

2. STRUCTURAL CHARACTERS OF THE LAVAS

Geikie (1897, 202) estimated the average thickness of the constituent lava flows in the Lower Basalts as fifteen feet. The 106 basalt flows measured by the writer at Islandmagee, Agnew's Hill, the Garron Plateau, the Giant's Causeway and in the mountains west of Belfast have an aggregate thickness of 2450 feet, giving an average thickness of twenty-three feet. This compares with the average of twenty-one feet for 109 flows in other parts of the Antrim Basalts from values recorded in the literature (Washing Bay bore, Wright, 1924; Aughrimderg bore, Hartley, 1948; Binevenagh, Slieve Gullion and Downhill, Patterson, 1955b, Hospers & Charlesworth, 1954).

Apart from a tendency for the flows of tholeiite to be thicker than those of olivine-basalt, there is little correlation between thickness of flows and composition of the rock. In general, however, the thinner the flow the coarser the rock, both being a function of the fluidity of the lava. The two most coarse-grained flows seen, of doleritic grain-size, each have a thickness of only ten feet, which is well below the average.

The thickest flow known to the writer is an olivine-basalt flow exposed on the Black Mountain west of Belfast. It attains a thickness of 150 feet. Several other flows have been found elsewhere with a thickness of about 100 feet.

It is seldom possible to trace a flow far on account of the usual lack of distinctive characters and the inadequacy of the exposures in most areas, but the following observations have been made:

A. A distinctive flow with sparse large feldspar phenocrysts is seen about 300 feet up in the lavas along the northern edge of the Garron Plateau, and has been traced continuously from the Inver River to near Garron Point, a distance of six miles. In this distance the thickness varies from sixty to eighty feet. Probably the same flow is seen again in the Cranny Water, four miles south of Garron Point.

B. On the Black Mountain, west of Belfast, a very thick flow (in places 150 feet thick) of olivine-rich basalt can be traced from Whiterock to Hannahstown, a distance of three miles. If, as seems likely, a flow with similar characters on Cave Hill is the same flow, the lateral spread is increased to six miles.

C. Three flows of olivine-rich basalt, fairly distinctive in the field and well exposed in a large number of quarries, can each be traced without difficulty from the White Mountain to Collin Glen, a distance of nearly four miles.

D. At the other extreme, a flow (continuous with its dyke-feeder) on the eastern shore of Brown's Bay, Islandmagee, has a lateral extent in the cliff section of only seventy feet, and attains a maximum thickness of ten feet. Other examples of flows and pahoehoe flow-units thinning out within a short distance are common around the coast of Islandmagee.

(a) Small-Scale Structures

Typically the uppermost quarter to a half of a lava flow is highly amygdaloidal. In addition there is a thin layer of amygdaloidal rock at the base. The amygdales are usually not more than several inches in diameter but exceptionally exceed one foot. Pipe amygdales are found in a large proportion of the flows, and are of two distinct types. Firstly there are the short pipes, found at the base of thin flows or flow-units of pahoehoe; they are usually about six inches long and quarter to half an inch in diameter, and two often coalesce upwards in an inverted Y. Secondly there are the long pipes which extend from bottom to top of a flow; they are about two inches in diameter but are usually pipe-like trains of small amygdales rather than continuous pipes, as illustrated by Shrock (1948, fig. 314).

The amygdales contain zeolites and other secondary minerals, namely calcite, aragonite, apophyllite, gyrolite, chalcedony, quartz, opal and mineraloids such as chlorophaeite. Empty vesicles are uncommon. The amygdale-minerals have a regular distribution which can be, and has been, mapped (Walker, 1951) and it is clear that the great bulk of them have crystallised very late in the volcanic history of the area.

Flow structures include occasional bending-over of short pipe-amygdales; the streaking-out of clusters of amygdales into bands which may alternate with bands of non-amygdaloidal rock; horizontal elongation of amygdales, in particular those in the interior of a flow; and parallel orientation of the tiny feldspar tablets in the more fine-grained basalts, usually resulting in a platy jointing. Many of the more fine-grained and olivine-rich basalts, such as are common on the higher ground in the east of Antrim, have a streaky flow-banding, well shown on weathered surfaces, with bands half an inch or so thick of slightly differing grain-size. The flow-banding is usually more or less parallel to the margins, but near the base of a flow it may be folded and contorted. Also indicative of flow is the occasional streaking-out of basalt pegmatites or bands of different rock-types, as exemplified by the composite lava flows (Fig. 5).

The best exposures for the study of the structure of lava flows are those along the sea coast of Islandmagee, and numerous examples have been found there of the uncovering of the ropy tops of flows of pahoehoe, one very accessible exposure being on the eastern shore of Ferris Bay. Cracks in the top of pahoehoe flows are often seen infilled from above with lateritic weathering products or later basalt. Aa is much less commonly seen than pahoehoe.

Columnar jointing is well developed only in the group of tholeiite flows along the north coast of Antrim (Tomkeieff, 1940b). Composition of the rock alone does not determine the nature of the jointing, for columnar jointing is also known in olivine-basalts, such as the basal flow in the main quarry at Whitehead and in a quarry on the western side of Muldersleigh Hill, north of Whitehead. It is also seen in a flow practically at the base of the lavas in the vicinity of Garron Point and again (if the flow is the same one) in a quarry on the west side of Glen Ballyemon. These occurrences of columnar flows at the base of a lava series, where they rest upon an eroded surface, may be significant. The writer considers that columnar jointing results when a lava is ponded in a surface depression, although it does not seem possible in Antrim to demonstrate decisively that this is so.

(b) Auto-Intrusions and Basalt Pegmatites

The phenomenon of auto-intrusion is comparatively seldom seen. One of the best examples is exposed in the coastal cliffs near the two-mouthed cave south-east of Portmuck, Islandmagee. The parent flow is a picrite-basalt[1] forty feet thick, and near the middle is a thin sheet of basalt much poorer in olivine and coarser in grain, and in composition corresponding roughly to the groundmass of the picrite-basalt. The two rocks are separated by a sharp but unchilled contact. This sheet can be traced laterally, varying in thickness from seventeen to twenty inches, for 400 feet before exposures fail. At one end the sheet descends abruptly in the lava, although unfortunately the base of the flow is below sea-level here; at this point, too, there is a vertical offshoot which gives off a number of thin sheets, as illustrated by the drawing, Fig. 2 a.

The field relations show clearly that the sheets were formed when the flow was still hot, and their great lateral extent indicates that the lava was still moving at that time, although perhaps in a very pasty condition, and one must suppose that the sheets obtained their material by squeezing-out from other more fluid parts of the flow.

Basalt lavas may have pegmatites, in the same way that granites may have associated pegmatites. Basalt pegmatites are characteristically somewhat coarser in grain than the parent basalt, and the contact is sharp and firmly welded but without any sign of chilling. The texture of the pegmatites is dominated by prismatic to subophitic titanaugite crystals several millimetres long, that are sometimes rimmed by a little aegirine-augite or aegirine. Associated with it are thin plates of ilmenite about the same size,

[1] The term picrite-basalt is applied here to those olivine-basalts which contain 30% or more by volume of modal olivine.

strongly zoned medium or sodic plagioclase feldspar, and an abun
zeolites in amygdales, in the groundmass of the rock, and repla
plagioclase, together with accessory apatite as long, slender need
pegmatites are usually olivine-free, but when olivine does occur it
fayalitic than in the basalts. Chemically the basalt pegmatites mu
an enrichment in titanium, sodium, water and perhaps iron as co
with the basalts.

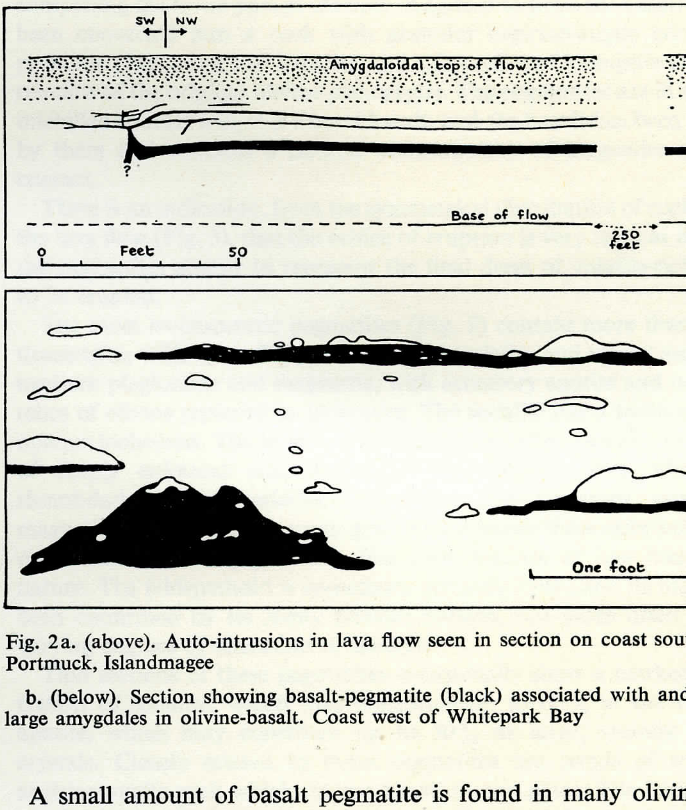

Fig. 2a. (above). Auto-intrusions in lava flow seen in section on coast sou
Portmuck, Islandmagee

b. (below). Section showing basalt-pegmatite (black) associated with and
large amygdales in olivine-basalt. Coast west of Whitepark Bay

A small amount of basalt pegmatite is found in many olivir
flows, as irregular veinlets, up to several inches thick; as planar sh
exceptionally extend laterally for as much as 100 feet; as small
intimately associated with amygdales (Fig. 2b); and as vertica
forming the matrix of pipe-amygdale trains. Probably the pegmatit
crystallised in a gas-rich environment, is derived by differentiatio
the basalt in which it occurs, and the genetic relationship is similar
between granite pegmatite and the granite in which it occurs.

(c) Alkaline Pegmatites

Quite unique, yet clearly closely related to the normal pegmatites in the basalts, are the feldspathoid-bearing pegmatites found in the lower component of the McIlroy's Port composite lava flow, Islandmagee, described on a later page. Mineralogically they are pyroxenites containing sodalite, the first record of this mineral in Ireland.

These pegmatites form irregular patches or veins up to two inches thick and are confined to a zone one foot thick (Fig. 4) in the olivine-rich basalt comprising the lower part of the flow. Adjacent to them the basalt itself has been converted into a rock with granular aegirine-augite enclosed by poikilitic plagioclase and sodalite, and a few relics of iddingsite are all that remains of the original olivine plenocrysts. The pegmatites are in sharp but unchilled contact with this altered basalt, and the basalt has been embayed by them and contains a notable concentration of magnetite along the contact.

There is an indication, from the symmetrical distribution of rock-units in the lava flow (Fig. 3), that the orifice of eruption is very close at hand, and the pegmatites appear to represent the final dregs of volatile-rich magma to be erupted.

The most melanocratic pegmatites (Fig. 9) contain more than 70% of titanaugite, with 10 to 20% of interstitial sodalite and minor amounts of medium plagioclase and magnetite, with accessory apatite and occasional relics of olivine replaced by iddingsite. The sodalite has a trellis of minute opaque inclusions. The least melanocratic pegmatites contain around 50% of deeply coloured and strongly zoned aegirine-augite, idiomorphic rhombdodecahedral sodalite, plagioclase and accessory apatite and magnetite. There is a continuous gradation between these extremes, and the more melanocratic pegmatite often rims patches of less melanocratic nature. The feldspathoid is sometimes perfectly fresh, and its identity has been confirmed by its X-ray powder pattern, but more often it shows varying degrees of alteration to zeolites.

Thin sections of these pegmatites occasionally show a marked concentration of sodalite, which may constitute up to 60% of the rock, and apatite, which may constitute up to 50% as large, stumpy euhedral crystals. Closely related to these pegmatites are bands of magnetite-aegirine augite rock which cut the basalt in one place. The feldspathoid-bearing pegmatites pass into normal basalt pegmatites composed essentially of plagioclase and titanaugite.

Chemical analyses of two specimens of pegmatite and of the enclosing picrite-basalt are presented in Table I, 1, 2 and 3. As compared with the picrite-basalt the pegmatites have a much lower content of silica and magnesia and show significant enrichment in lime and titania and higher state of oxidation of the iron.

TABLE I. **Chemical Analyses**

	1	2	3	4	5
SiO_2	40.71	39.26	45.67	42.6	45.7
TiO_2	2.38	1.25	.76	.67	1.3
Al_2O_3	12.75	18.33	13.46	9.6	16.8
Cr_2O_3	—	—	.31	—	—
Fe_2O_3	6.12	6.29	1.33	2.4	1.8
FeO	5.55	1.97	8.65	10.0	9.2
MnO	.29	.32	.18	.16	.15
MgO	9.77	7.24	16.30	22.8	9.6
CaO	18.56	15.58	9.74	5.7	10.5
Na_2O	1.71	3.26	1.53	1.2	2.5
K_2O	.01	.35	.14	.25	.27
P_2O_5	.13	.22	.11	.06	.12
H_2O^+	1.78	4.55	.87	4.0	1.4
H_2O^-	.07	.99	.39	—	—
CO_2	.15	.36	—	—	—
F	—	tr.	—	—	—
Cl	—	.37	—	—	—
SO_4	—	tr.	—	—	—
	100.01	99.86	99.54	99.4	99.3
D	—	—	—	2.93	2.97

1. Titanaugite pyroxenite pegmatite with sodalite, south of vent, McIlroy's Port, Islandmagee. Analyst: M. H. Kerr.

2. Aegirine-augite pegmatite rich in sodalite, same locality. Analyst: M. H. Kerr.

3. Picritic olivine-basalt, lower component of McIloy's Port composite lava flow, just south of vent. Analyst: M. H. Kerr. Modal analysis, Table II, 1b.

4. Picrite-basalt, lower component of composite lava flow, Cranny Water, Carnlough. Analyst: P. J. Curtis. Modal analysis, Table II, 2a.

5. Olivine-basalt layer in composite lava flow, Cranny Water, Carnlough. Analyst: P. J. Curtis. Modal analysis, Table II, 2b.

(Analyses 4 and 5 by methods based on Shapiro & Brannock, as modified at Imperial College.)

3. COMPOSITE LAVA FLOWS

A number of examples are known in Antrim of lava flows made of two rock-types, namely olivine-rich basalt (picrite-basalt) and relatively olivine-poor basalt. For some, Tomkeieff (1934) has ascribed this to gravity-settling of olivine crystals in place. In others, however, there is a sharp contact between the two rock-types and the conditions attached by Kennedy (1931) to the definition of a composite lava flow are satisfied, namely that the flow consists of two readily recognisable rock-types, arranged asymmetrically, unchilled against one another, and without any intervening slag. Composite lava flows have not hitherto been recorded from Ireland.

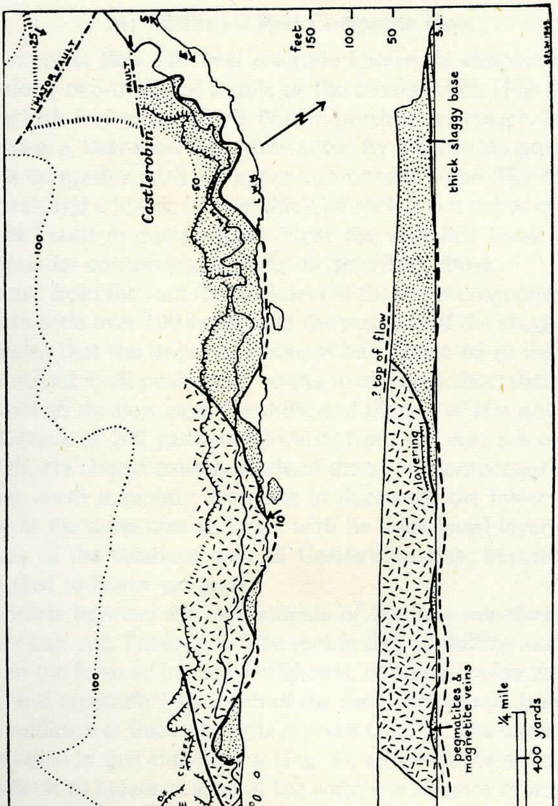

Fig. 3. Map and section of the McIlroy's Port composite lava flow, Islandmagee

(a) McIlroy's Port Composite Flow

This composite flow, the best example known, is almost continuously exposed along two-thirds of a mile of the coastal cliffs (Fig. 3) on either side of the little bay of McIlroy's Port in north Islandmagee. In the centre of the exposure, near where the flow is cut by a probable explosion vent, the flow is composite with an upper component some fifty feet thick of olivine-basalt and a lower, ten feet thick, of rock much richer in olivine and near picrite-basalt in composition. Near the vent this lower component bears pegmatites containing sodalite, as described above.

Southward from the vent the thickness of the lower component increases to 40 feet in little over 100 yards, and the position of the slaggy top of the flow indicates that the upper component has decreased in thickness by a like amount and in all probability comes to an end a short distance farther south, although the flow caps the cliffs, and the top of it is not seen.

To a distance of 200 yards northwards from the vent the coastal cliffs, 50 feet high, are almost entirely made of the upper component of the flow, but farther north it rapidly decreases in thickness, the lower component increasing at the same time to form, with its thick basal layer of slag, the entire mass of the headland east of Castlerobin Bay, beyond which the flow is faulted to below sea-level.

The contacts between the components of the flow are always perfectly sharp and clean-cut. There is no intervening slag or chilling and there is no evidence, in the form of intrusive offshoots, of any intrusive relationships. In places, and especially just south of the vent, the contact is marked by a layer two millimetres thick of augite crystals (Fig. 9). The contact relations are best studied in this cliff-section (Fig. 4), although the actual contact is at first difficult to locate in view of the complete absence of any difference in jointing or resistance to weathering of the two rocks.

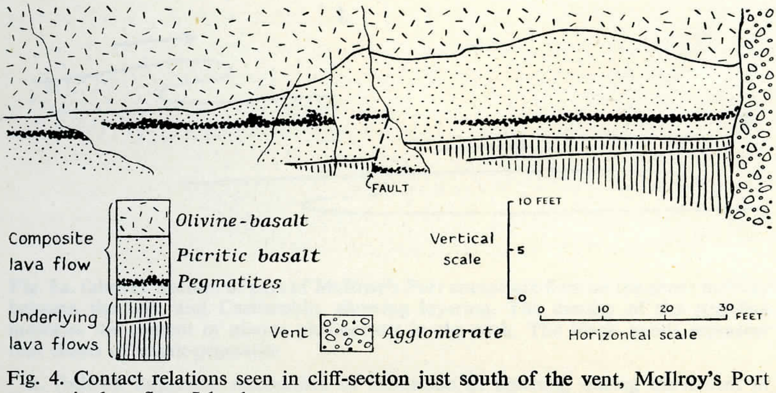

Fig. 4. Contact relations seen in cliff-section just south of the vent, McIlroy's Port composite lava flow, Islandmagee

The lower component of the McIlroy's Port flow is an olivine-rich basalt or picrite-basalt with corroded phenocrysts of olivine up to three millimetres making up some 30% of the volume of the rock. The groundmass is very fine-grained and consists of labradorite and pale brown augite in roughly equal amounts, together with a little olivine and magnetite. The rock is often markedly streaky, with an alternation of bands an inch or so thick in which the groundmass varies in grain-size. Some bands contain minute vesicles.

The upper component of the flow is a coarse-grained olivine-basalt with strongly zoned plagioclase, olivine in ragged micro-phenocrysts that are usually altered to bowlingite, chlorite or iddingsite, and granular pyroxene, together with occasional ill-formed micro-phenocrysts of augite. The pyroxene in the flow is a normal titanaugite with $2V_\gamma = 48–54°$ and $\beta =$ about 1.690, but in the upper component there is also a little pigeonite with $2V_\gamma = 10–20°$ and with the optic axial plane parallel to 010. One crystal was seen of augite mantled by pigeonite and separated from it by a sharp contact.

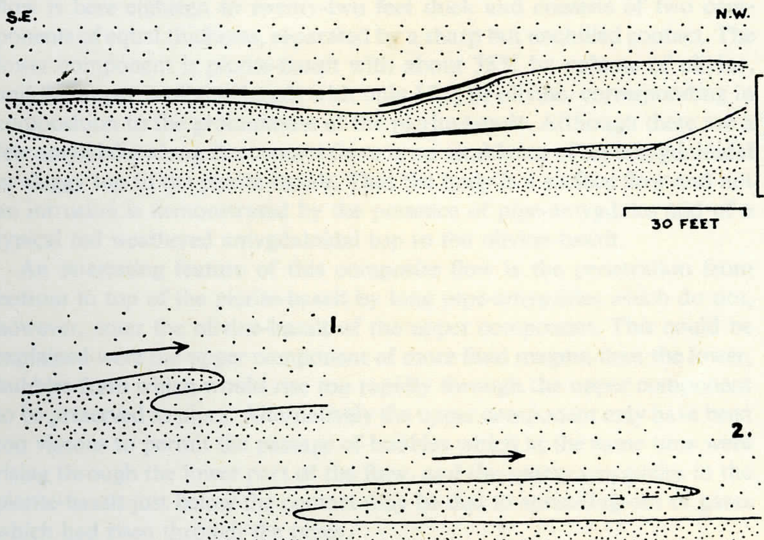

Fig. 5a. (above). Section of part of McIlroy's Port composite flow on the shore midway between the vent and Castlerobin, showing layering. The density of the stippling indicates the content of olivine phenocrysts in the rock. The black bands represent thin sheets of basalt-pegmatite

b. (below). Suggested mechanism of formation of layering, during movement of composite lava

A form of layering is developed in the flow some 200 yards north of the vent. The flow here consists of three or four components, separated by perfectly sharp contacts. The lowest is picrite-basalt, and the highest olivine-basalt, both apparently homogeneous, but between them is a layer of olivine-basalt grading upwards by increase in olivine into picrite-basalt, and at one place there are two such layers, as illustrated by the diagram, Fig. 5. At the same place there are several planar sheets one to two inches thick of basalt pegmatite parallel to the contacts between the components.

It is suggested that the layering at this locality is due to drag-folding and thrusting caused by olivine-basalt magma flowing over picrite-basalt, with intermixing along the 'thrust' to give the observed upward increase in olivine, as presented by the diagrams, Fig. 5 b.

(b) The Lurigethan Composite Flow

A second composite flow is exposed practically at the top of the precipitous escarpment bounding the Glenariff Valley on the west, at the point where a stream has cut a gully, two miles SSW. of Lurigethan summit. The flow is here eighteen to twenty-two feet thick and consists of two components of equal thickness, separated by a sharp but unchilled contact. The lower component is picrite-basalt with about 35% by volume of olivine, and the upper is olivine-basalt with only 15% of olivine, corresponding in composition to the groundmass of the picrite-basalt. Although there are a few amygdales along the contact there is no semblance of an amygdaloidal or slaggy top to the picrite-basalt. That the body is a surface flow and not an intrusion is demonstrated by the presence of pipe-amygdales and of a typical red weathered amygdaloidal top to the olivine-basalt.

An interesting feature of this composite flow is the penetration from bottom to top of the picrite-basalt by long pipe-amygdales which do not, however, enter the olivine-basalt of the upper component. This could be explained were the upper component of more fluid magma than the lower, bubbles from which would rise too rapidly through the upper component to be preserved as pipes. Alternatively the upper component may have been too viscous to permit the passage of bubbles which at the same time were rising through the lower part of the flow, and the sparse amygdales in the picrite-basalt just below the contact may be due to spreading-out of gases which had risen through the pipes.

A second exposure, probably of the same composite lava flow, has been found two miles away in Glenariff Glen, in the path fifty yards above Esse-na-Laragh waterfall. Here the lower component, which is a perfectly fresh picrite-basalt, is about five feet thick, and the upper component, of olivine-basalt, is eight feet thick, the contact between these rock-types being gradational over two inches. Again the lower component is penetrated from bottom to top by long pipe-amygdales which do not, however, enter the upper component.

TABLE II. **Modal Analyses of Composite Lavas**

	1a	1b	2a	2b	3a	3b	4a	4b	5a	6a	6b
Olivine	31	12	45	21	34	14	43	21	35	38	14
Plagioclase	34	54	32	50	32	38	32	49	25	47	55
Augite	33	31[1]	14	25	25	33	13	23	23	12	27
Fe ore	2	3	2	3	3	4	2	2	2	3	4
Zeolites } Chlorite }	0	0	7	1	6	11	10	5	15	0	0

1. McIlroy's Port composite flow. a: picrite-basalt; b: olivine-basalt.
2. Cranny Water composite flow. a: picrite-basalt; b: olivine-basalt.
3. Lurigethan composite flow. a: picrite-basalt; b: olivine-basalt.
4. Skerrywhirry composite flow. a: picrite-basalt; b: olivine-basalt.
5. Composite flow below McIlroy's Port flow. Picrite-basalt.
6. Corkey dolerite intrusion. a: olivine-rich facies near margin of dolerite; b: relatively olivine-poor facies in centre of the intrusion.

The modes were determined by integrating stage, each on two or more thin sections of the rock and are expressed in volume percentages. Note: 1a, 2a and 2b have been analysed chemically, Table I.

[1] Includes a little pigeonite.

(c) Cranny Water Composite Flow

This flow, exposed on either side of Cranny Water, two miles west of Carnlough, is at least 100 feet thick, and being practically at the base of the Upper Basalts it forms a prominent rocky scarp overlooking the marked bench due to erosion of the laterites of the interbasaltic zone. The flow is of picrite-basalt with up to 50% of olivine passing upwards into a rock rather less rich in olivine. Near the base of the flow the picrite-basalt contains a layer six to ten feet thick of basalt free from olivine phenocrysts. This layer has a known lateral extent of half a mile. The basalt layer is similar in texture and composition to the groundmass of the picrite-basalt.

The basalt layer presents against the picrite-basalt a sharp upper contact and a lower contact which is gradational over one inch. Both contacts are unchilled and the two rocks are firmly welded together and show no differences in jointing or weathering. The contacts have to be searched for carefully in the field, and are not visible from a distance of more than two or three feet.

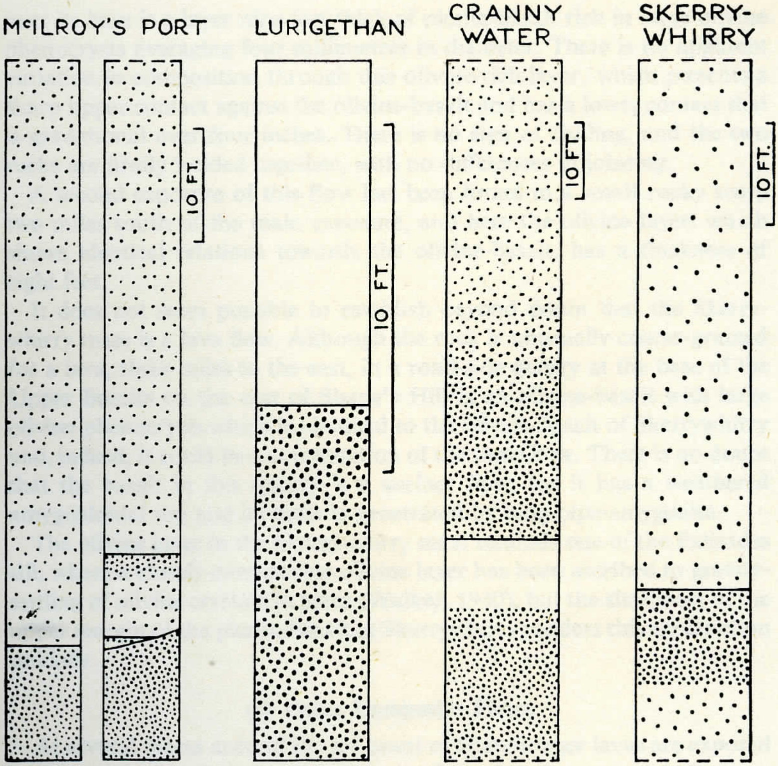

Fig. 6. Comparative vertical sections of four composite lava flows. Density of stippling indicates the relative abundance of olivine phenocrysts

Chemical and modal analyses of the two components of this flow are presented in Table I, 4 and 5, and Table II, 2a and 2b. The picrite-basalt is more than twice as rich in olivine as the olivine-basalt, and this is reflected chemically in its much higher content of magnesia and lower content of silica and alkalies. The high water content of the picrite-basalt is due to a considerable content of zeolites in the groundmass of the rock.

(d) The Skerrywhirry Composite Flow

The fourth example of a composite flow is perhaps afforded by the mass of basalt forming the prominent rocky escarpment of Skerrywhirry, at the base of the Upper Basalts several miles west of Larne. The rock is a coarse-grained olivine-basalt bearing sparse large olivine phenocrysts which increase slightly in amount downwards. Within the olivine-basalt near its base is a layer nine feet thick of picrite-basalt rich in large olivine phenocrysts averaging four millimetres in diameter. There is no apparent variation in composition through this olivine-rich layer, which presents a sharp upper contact against the olivine-basalt and has a lower contact that is gradational over four inches. There is no sign of chilling, and the two rocks are firmly welded together, with no differences in jointing.

A second exposure of this flow has been found in a small rocky scarp two miles south of the main exposure, and here the olivine layer, which shows identical relations towards the olivine-basalt, has a thickness of eight feet.

It does not seem possible to establish beyond doubt that the Skerry-whirry mass is a lava flow. Although the rock is unusually coarse-grained for a lava, three miles to the east, in a road-side quarry at the base of the Upper Basalts on the east of Shane's Hill is an olivine-basalt with large olivine phenocrysts which is identical to the olivine-basalt of Skerrywhirry and, indeed, it could be a continuation of the same flow. There is no doubt that the basalt in this quarry is a surface flow, for it has a weathered amygdaloidal top and its mass is penetrated by long pipe-amygdales.

The olivine layer in the Skerrywhirry mass reminds one of the Palisades sill, where a closely comparable olivine layer has been ascribed to gravity-settling of olivine crystals in place (Walker, 1940), but the sharpness of the upper margin of the picrite-basalt at Skerrywhirry renders this explanation unlikely.

(e) Other Composite Flows

At several places around the sea coast of Islandmagee lavas are exposed with a picrite-basalt lower part and an olivine-basalt upper part. In some this may be due to gravity-settling of olivine crystals (Tomkeieff, 1934) in place, but in others the contact between the two rocks is sharp, although firmly welded and unchilled. A readily accessible example is seen in McIlroy's Port just below the main composite flow there. In this case the picrite-basalt bears some 35% of olivine, the olivine-basalt about 15%, and the contact is quite irregular.

(f) Discussion

The composite flows described above all contain two very similar rock-types, but as may be seen from the comparative sections of Fig. 6 they differ in the arrangement of these rock-types. In all, however, the contacts are typically sharp or gradational over a very short distance, and they are unchilled and the two rocks are firmly welded together. The rock-layers are planar in form, and without intervening slag.

It is clear that gravity-settling of olivine crystals in place is quite incapable of accounting for all these characteristics and one has to postulate that in each case the two contrasting rock-types reached their present position as two separate lava types. These may have arisen by differentiation from a common parent, probably by simple gravity-sinking of olivine phenocrysts, but such differentiation must have been essentially complete before the lavas reached their present position; that is, before movement of the lava had ceased. It does not seem possible to decide whether this differentiation took place before the magma reached the surface or afterwards, but the former is possible, and it may be significant that several of the dolerite plugs in Antrim have an olivine-rich facies near the margin probably due to differentiation during the uprise of the magma in the conduit.

4. DYKES

Associated with the lavas is a swarm of dykes with predominant NNW. or NW. trend, the swarm being most intense in the vicinity of Belfast. The accompanying map, Fig. 1, indicates the distribution of the dykes. The intensity of the swarm ranges from one to thirty or forty dykes per mile, representing a crustal stretch of up to 6%, and the inset to Fig. 1 gives an indication of the distribution of intensity of the swarm expressed as percentage stretch. The intensity probably falls off upwards in the lavas, but exposures are not sufficiently good to enable this to be established.

There are a few dykes which trend approximately at right angles to the swarm, and the following data may indicate that they form a distinct and separate earlier sub-swarm:

A. The dyke feeding a lava flow very low in the lava series on the eastern shore of Brown's Bay, Islandmagee, trends a little S. of W.

B. In Triassic rocks on the shore near Greenisland, seven miles north of Belfast, an ENE. dyke is cut by one trending NNW.

C. In a Chalk quarry at Bellevue, Belfast, a NE. dyke is cut by one trending NW.

D. A NE.-trending dyke one-quarter mile NE. of the White Mountain in the south of Antrim and near the base of the lava succession contains amygdales up to six inches in diameter. These amygdales, larger than any seen in other dykes in Antrim, may indicate the close proximity of the land surface at the time of intrusion of the dyke. The other dykes in the area trend NW. and have small amygdales, being probably intruded when the land surface had been built to a higher level.

The radiating arrangement of dykes around a focus in mid-Antrim suggested by Charlesworth & Hartley (1935) has not been established.

The great majority of the dykes are normal olivine-dolerites of very uniform composition, with basaltic chilled edges. Many have layers of zeolite-filled amygdales parallel to their margins, and often the rock is crinanitic and has zeolites in the groundmass. Prismatic jointing normal to the margins is commonly seen, and one of two types of platy jointing, either parallel to the margins or normal to them and steeply inclined. The attitude of the last is perhaps related to the direction of flow of magma in the dyke-fissure.

Measurement of ninety dykes gives nine feet as the average thickness. Individual dykes can seldom be traced far, largely due to inadequate exposures, but one, the Waterfoot dyke, can be traced for four miles, and other dykes have been traced for distances of up to two miles.

An echelon arrangement is often seen. Where dykes cut the Chalk or Triassic marls they are often extremely irregular in form, with numerous offshoots and protuberances and often a pronounced echelon arrangement. The extreme of irregularity is illustrated by a dyke exposed above the old chalk quarry a short distance north-east of the lower entrance to Glenariff Glen tourist path. Where it cuts basalt lavas this dyke is very regular, but in the Chalk it splits into dozens of sub-parallel veinlets an inch or two thick.

The metamorphism produced by dykes is normally small. The Chalk is recrystallised to a fine-grained, saccharoidal marble to a few inches and rarely to a few feet from the contact; red Triassic marls and sandstones may be decolorised, with local development of poikilitic calcite crystals in sandstones; and basalt lavas are occasionally reddened. Exceptional is the large-scale zeolitisation of lavas and the development of andradite, apatite, magnetite and other minerals in the lavas and underlying sedimentary rocks by dykes at Portmuck, Islandmagee (Walker, 1948), and the pronounced metamorphism of Triassic sandstones (Reynolds, 1940), Old Red Sandstone and basalt lavas by the Waterfoot dyke.

Dykes and Fissure-Eruption

On the western shore of Brown's Bay, Islandmagee, is a particularly convincing example of a lava flow in visible connection with its dyke-feeder. The lava flow in question is in the Lower Basalts about fifty feet above the underlying Chalk, and can readily be located with reference to its position some twenty yards north of the Rocking Stone, a large glacial erratic which forms an unusually convenient landmark.

The flow is of very limited lateral extent, and attains a maximum thickness of ten feet (Fig. 7). It is continuous with a fifteen-inch dyke that cuts vertically through the lower flows and trends a few degrees south of west. The extrusive nature of the lava is clearly indicated by the presence of a red weathered amygdaloidal top, by the absence of cross-cutting relationships and offshoots from the top, and by the local development of pipe-amygdales along the base.

The dyke-feeder is exposed through only a small vertical height, but appears to increase somewhat in thickness downwards. That it constitutes a true dyke and not a fissure in the underlying flow filled from above is indicated by the two wedge-shaped offshoots into the top of the underlying flow. This evidence is significant in view of the fact that such cracks filled from above are common in the lavas of Antrim; the writer considers it very probable that the locality claimed by Patterson (1950) as an example of fissure-eruption is such an instance of infilling from above of cracks in the bulbous front of pahoehoe flow-units.

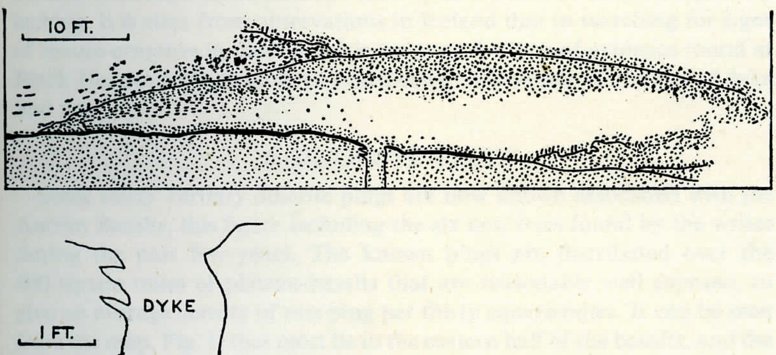

Fig. 7. Section of fissure-erupted lava flow, Brown's Bay, Islandmagee. Stippling indicates amygdales. Below: detail of join of dyke and lava

Petrographically the lava is a normal, medium-grained olivine-basalt consisting of small olivine replaced by iddingsite, normally zoned labradorite, ophitic titanaugite and accessory magnetite together with an abundance of secondary minerals in amygdales and replacing the primary constituents of the rock. The dyke is of similar composition but rather finer in grain, with a little glass at the contact. Both dyke and lava contain numerous zeolite-bearing amygdales up to half an inch in diameter.

The great scarcity of known examples of lavas in visible connection with their dyke-feeder in the Thulean Province has often aroused comment (Tyrrell, 1937). The writer's experience in the post-glacial lava fields of Iceland suggests that when a fissure-eruption takes place lava and dyke-feeder often may not remain in continuity, but may be separated by the scoriaceous basalt of the spatter rampart, spatter craters or cinder cones that are usually built along the line of the fissure.

About 300 yards north of Black Head on the coast of Islandmagee there is a section in the raised beach cliffs of what appears to have been a cinder cone at least twenty feet high resting upon a flat platform of lavas. The cone is a confused jumble of irregular pieces of basalt, mostly amygdaloidal, ranging in size from a few inches to over one foot. A crude stratification parallel to the sides of the cone is marked by layers of blocks of different size.

On the southern slope of the cone is a group of very thin lavas in which the sharp bending-over of the basal pipe-amygdales attests to the movement of the lava down the side of the cone. Lavas and cone are cut by a cluster of dykes, and one of the thin flows resting on the cone on its south side may possibly be continuous with one of the dykes, although this is not certain. Although proof that this locality is the seat of fissure-eruption is lacking, it is clear from observations in Iceland that in searching for signs of fissure-eruption in older basaltic terranes the type of evidence found at Black Head is perhaps more to be expected than visible continuity of dyke and flow.

5. DOLERITE PLUGS

Some thirty Tertiary dolerite plugs are now known associated with the Antrim Basalts, this figure including the six new ones found by the writer during the past few years. The known plugs are distributed over the 800 square miles of plateau-basalts that are reasonably well exposed, to give an average density of one plug per thirty square miles. It can be seen from the map, Fig. 1, that most lie in the eastern half of the basalts, and the density there is nearer one plug per twenty square miles.

The following are the newly discovered plugs:

A. Corkey, a plug of olivine-dolerite with olivine-rich facies near the margin, passing upwards into a sill in basalt lavas. The intrusion forms the hill (including Craigacullin) NE. of Corkey, nine miles E. of Ballymoney in NE. Antrim.

B. Glasmullen, a small plug of olivine-free dolerite in basalt lavas, on the plateau SE. of Crockalough, two miles SSW. of Lurigethan summit.

C. Doonbought, discovered independently by E. M. Patterson (personal communication) and the writer, a small plug of ophitic olivine-dolerite in basalt lavas, six miles north of Ballymena.

D. Trosk, an elongated plug of picrite-dolerite in Upper Basalts, one-quarter mile north of Loughnatrosk and two miles NNW. of Carnlough village, E. Antrim.

E. Ticloy, an elongated plug of olivine-dolerite in basalt lavas, crossing the stream, Ticloy Water, three-quarters of a mile E. of Ticloy Hill, and four miles SW. of Carnlough.

F. Parkgate, an elongated plug of olivine-dolerite in basalt lavas on the eastern side of Donegore Hill with a second small plug to the north, two and a half miles NNW. of Templepatrick.

The comparative plans of Fig. 8 give an indication of the range of size and shape of these intrusions. It can be seen that the average diameter is of the order of 200 to 300 yards and that most are elongated NW. or NNW.

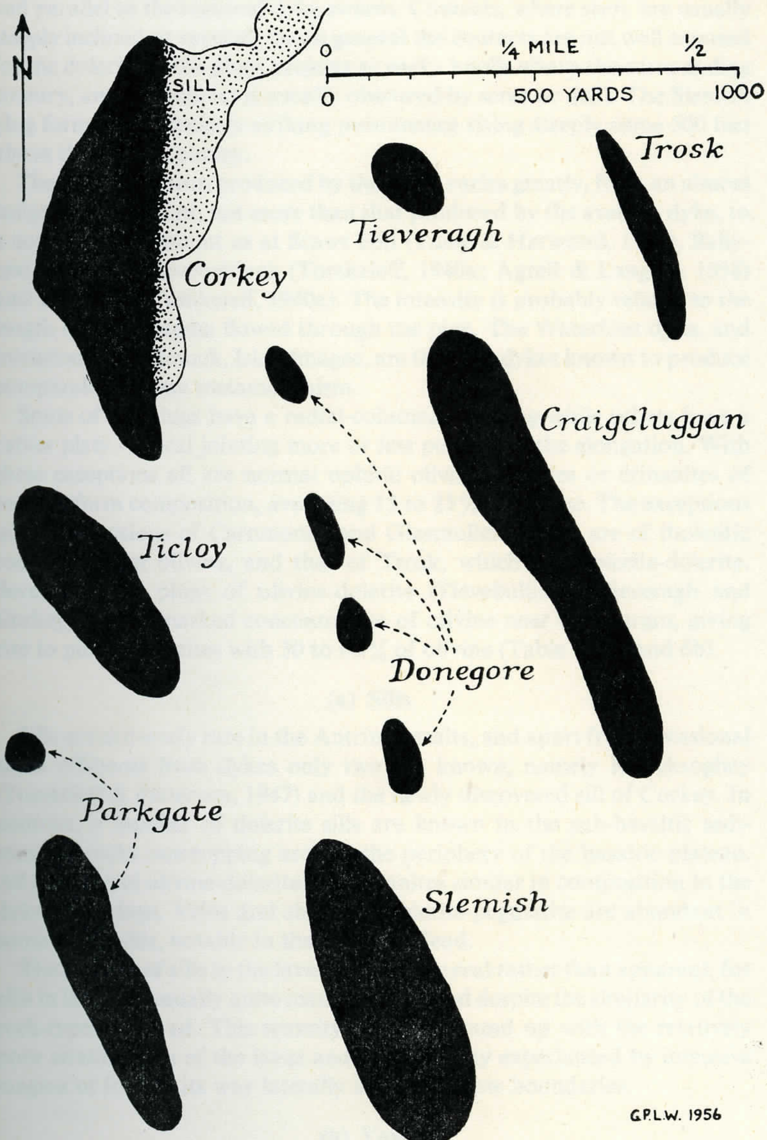

Fig. 8. Comparative plans of dolerite plugs in Antrim

and parallel to the regional dyke swarm. Contacts, where seen, are usually steeply inclined or vertical, but in general the contacts are not well exposed for the dolerite of the plugs projects as rocky knolls above the surrounding country, and the contact is usually obscured by scree or drift. The Slemish plug forms a particularly striking prominence rising steeply some 500 feet above the basalt country.

The metamorphism produced by the plugs varies greatly, from an almost insignificant amount, not more than that produced by the average dyke, to a considerable amount as at Scawt Hill (Tilley & Harwood, 1931), Ballycraigy Bridge, Tievebulliagh (Tomkeieff, 1940a; Agrell & Langley, 1958) and Tieveragh (Tomkeieff, 1940a). The intensity is probably related to the length of time magma flowed through the pipe. The Waterfoot dyke, and intrusions at Portmuck, Islandmagee, are the only dykes known to produce comparably intense metamorphism.

Some of the plugs have a radial-columnar jointing while others have a rather platy vertical jointing more or less parallel to the elongation. With three exceptions all are normal ophitic olivine-dolerites or crinanites of very uniform composition, averaging 15 to 25% of olivine. The exceptions are the intrusions of Carnmoney and Glasmullen, which are of tholeiitic rock free from olivine, and that of Trosk, which is of picrite-dolerite. Several of the plugs of olivine-dolerite (Tievebulliagh, Tieveragh and Corkey) have a marked concentration of olivine near the margin, giving rise to picrite-dolerites with 30 to 60% of olivine (Table II, 6a and 6b).

(a) Sills

Sills are extremely rare in the Antrim Basalts, and apart from occasional small offshoots from dykes only two are known, namely Knocksoghey (Tomkeieff & Patterson, 1947) and the newly discovered sill of Corkey. In contrast, a number of dolerite sills are known in the sub-basaltic sedimentary rocks outcropping around the periphery of the basaltic plateau. All are normal olivine-dolerites or crinanites similar in composition to the dykes and plugs. Veins and sheets of dolerite-pegmatite are abundant in some of the sills, notably in that of Fair Head.

The scarcity of sills in the lavas is probably real rather than apparent, for sills in lavas are usually quite readily recognised despite the similarity of the rock-types involved. This scarcity must be bound up with the relatively poor stratification of the lavas and the difficulty experienced by intrusive magma of forcing its way laterally along the flow boundaries.

(b) Vents

In no case is it possible to demonstrate continuity between plug and lava flow, although the intense metamorphism around some plugs must indicate copious eruptions of basaltic magma from them. Direct evidence that some of the plugs communicated with the surface in Tertiary times is found in the association of some with agglomerate.

The best-known agglomerate-filled vent is that of Carrickarade on the north coast of Antrim (Symes, Egan & McHenry, 1888; Tomkeieff & Patterson, 1948), with bedded ash in the lava succession near by. Rohleder (1925), Dawson (1951) and Patterson (1955a) have interpreted as agglomerate-filled vents a number of occurrences of basalt breccia in the north of Antrim, and the present writer knows of similar occurrences along the coast north-west of Larne. It seems more likely, however, that these breccias are due to collapse of basalt into solution pipes in the Chalk (Charlesworth, 1935) or are rootless vents and are not related to the conduits that brought the lava to the surface.

Along the western edge of the dolerite mass of Ballygalley Head is a belt some fifty to a hundred yards wide of agglomerate containing fragments of Chalk, Trias and basalt. This agglomerate, not hitherto described, is closely similar in character to some of the agglomerate near Carrickarade on the north coast of Antrim. Two miles west of Ballygalley Head, very low down in the lava succession on the escarpment of Knock Dhu, there is a bed at least twenty feet thick, for the most part obscured by scree, of chalky agglomerate of identical characters to that associated with the dolerite. There is no proof that the two are related, but it seems very likely that they are, and that the bedded agglomerate of Knock Dhu was erupted from the Ballygalley Head vent.

The attitude of platy jointing parallel to the margin and columnar jointing normal to it suggests that the dolerite mass of Ballygalley Head may not be a vertical plug with cylindrical shape, as proposed by Tomkeieff (1935) but rather funnel-like or cup-like in form, and perhaps even a crater-filling.

(c) Re-interpretation of the Donegore Dyke

The Donegore dyke, some miles north-west of Belfast, was first studied by Hull, Duffin & Du Noyer (1876) of the Geological Survey of Ireland. It was later remapped by Cole (1912, 93) who described the intrusion as a NNW.-trending dyke. A critical re-examination of the exposures appears to necessitate modification of this interpretation of the form of the dolerite.

Exposures of the Donegore dyke are confined to four rocky knolls aligned NNW. along a distance of two-thirds of a mile. The writer believes that these represent four separate dolerite plugs (Fig. 8). Proof, in the exposure of basalt lavas between the knolls, is absent, but in two of the knolls in which the dolerite is banded the banding is concentric with the edge of the knoll and inclined inwards in funnel-like fashion. This is strongly suggestive of each knoll being a separate entity. The banding is best seen in the southernmost knoll, The Craig. The bands, an inch or two

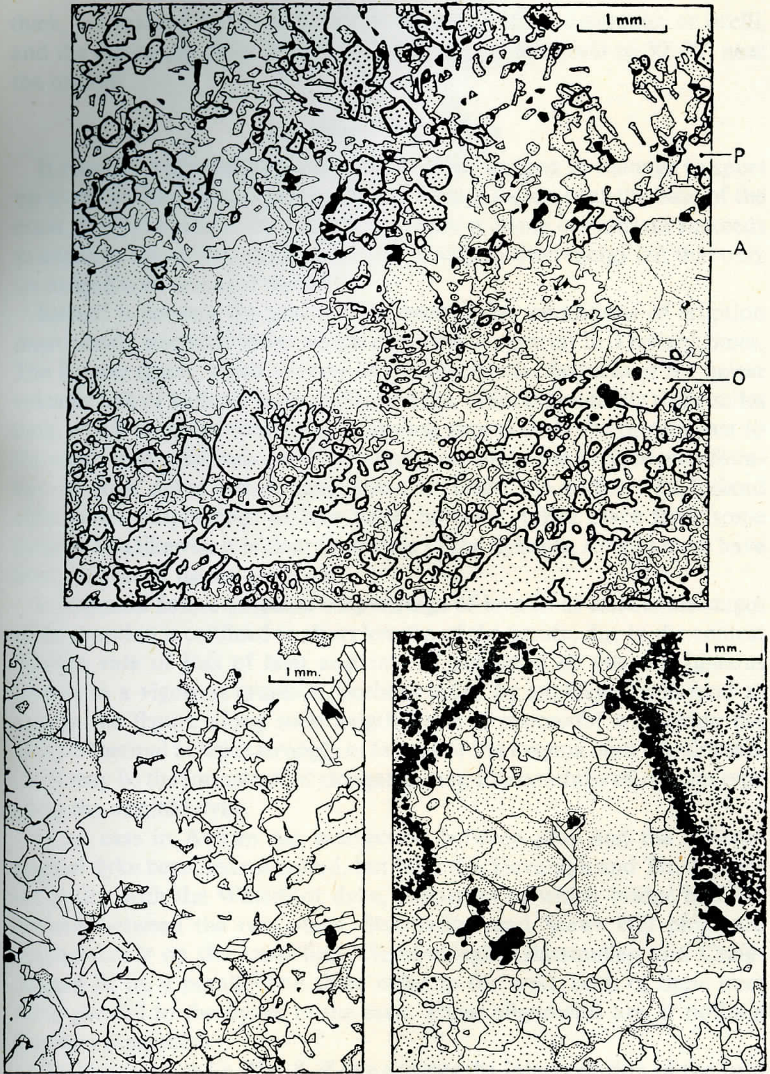

Fig. 9. Thin sections of rock from the McIlroy's Port composite lava flow, Islandmagee

Above: Contact between two components, shore just south of vent. Olivine-basalt above, picrite-basalt below, with layer of augite along contact. O = olivine, A = augite, P = plagioclase

Below, left: Sodalite-rich pegmatite. Sodalite, blank; aegirine-augite, stippled (the density of the stippling indicating the depth of colour in zoned crystals); plagioclase, lined

Below, right: Pegmatite rich in pyroxene in contact with altered basalt on either side. The basalt is a fine-grained aggregate of aegirine-augite and sodalite, liberally dusted with magnetite, with a marked concentration of magnetite at the contact thick, are marked by the presence or absence of tiny amygdales or ocelli, and the dip ranges from 10–30° near the edge of the knoll to 30–70° near the middle.

(d) Origin of the Plugs

It requires a considerable effort for basaltic magma to manage to spurt up to the surface along a narrow fissure from a region near the base of the crust. In all probability the magma of a dyke in many cases never succeeds in attaining the surface at all, or reaches it with so little energy left that only an insignificant eruption occurs.

Iceland is perhaps the place where present-day conditions of eruption most closely resemble those which obtained in Antrim in Tertiary times. The fissures (gjás), which are one of the spectacular features of the newer volcanic belt of Iceland, form gaping cracks, often individually some miles long, which cross the country in a curving swarm from the north coast to the south-west peninsula, and are almost certainly the surface manifestation of such dykes which have failed to reach the surface. In Iceland voluminous outpourings of lava have, however, taken place from some fissures, and likewise it is clear that some of the dykes in Antrim must have been the seat of fissure-eruption.

In a typical fissure-eruption outpourings of lava in at least some stages of the eruption is confined to short lengths of the fissure, due to the contest between rate of loss of heat and rate of accession of magma. Igneous erosion in a vigorous eruption, perhaps aided by explosion, will tend to enlarge the fissure along such lengths, and if successful will swing the delicate thermal balance strongly in favour of the magma, and the ultimate result may be the formation of elongated plug-like conduits of Antrim type along the original dyke.

In no case in Antrim has connection between plug and the inferred original dyke been demonstrated, but both the Tieveragh and Trosk plugs are in line with the Waterfoot dyke, exposures of which bridge half the distance between the two plugs. Straidkilley and Scawt Hill plugs are approximately on the same line, Tievebulliagh, Glassmullen and Craigcluggan lie on a parallel line three miles to the west, both of these lines being parallel to the dykes in the area. These alignments are, if nothing else, very suggestive.

The Donegore dyke, Fig. 8, if one accepts the interpretation of the field relations put forward in this paper, can perhaps be regarded as an early stage in the development of an elongated plug; the four separate plugs have not coalesced. The Parkgate plug, with its solitary satellite plug to the north, is an intermediate stage, and the Craigcluggan plug may be regarded as representative of the final stage in the evolution of an elongated plug of Antrim type from a dyke.

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REFERENCES

AGRELL, S. O. & J. M. LANGLEY. 1958. The Dolerite Plug at Tievebulliagh, near Cushendall, Co. Antrim. *Proc. R. Irish Acad.*, B, **59,** 93–127.

CHARLESWORTH, J. K. *et al.* 1935. The Geology of North-East Ireland. *Proc. geol. Ass., Lond.*, **46,** 441–502.

——— & J. J. HARTLEY. 1935. The Tardree and Hillsborough Dyke Swarms. *Irish Nat. J.*, **5,** 193–6.

CLELAND, A. McI. 1928. 'Flour' of Flint. *Irish Nat. J.*, **2,** 204–7.

———. 1930. Recent Rock Exposures at Magheramorne Quarries. *Irish Nat. J.*, **3,** 101–5.

———. 1933. An Interesting Rock Exposure at Whitehead. *Irish Nat. J.*, **4,** 209–11.

COLE, G. A. J. *et al.* 1912. The Interbasaltic Rocks of North-East Ireland. *Mem. geol. Surv. U.K.*

DAWSON, J. 1951. The Brockley Dolerite Plug and the Church Bay Volcanic Vent, Rathlin Island. *Irish. Nat. J.*, **10,** 157–63.

EYLES, V. A. 1952. The Composition and Origin of the Antrim Laterites and Bauxites. *Mem. geol. Surv. U.K.*

FOWLER, A. 1957. *Summ. Progr. geol. Surv. Lond. 1956,* 48–9.

GEIKIE, A. 1897. *The Ancient Volcanoes of Great Britain,* 2. London.

HARTLEY, J. J. 1948. The Post-Mesozoic Succession South of Lough Neagh, Co. Antrim. *Irish Nat. J.*, **9,** 115–21.

HAWKES, L. 1916. The Building of the North Atlantic Tertiary Volcanic Plateau. *Geol. Mag.*, **53,** 385–95.

HOSPERS, J. & H. A. K. CHARLESWORTH. 1954. The Natural Permanent Magnetisation of the Lower Basalts of Northern Ireland. *Mon. not. R. astr. Soc., Geophys. Suppl.*, **7,** 32–43.

HULL, E., W. E. L'E. DUFFIN & G. V. DU NOYER. 1876. Explanatory Memoir to Sheets 21, 28 and 29. *Mem. geol. Surv. U.K.*

KENNEDY, W. Q. 1931. On Composite Lava Flows. *Geol. Mag.*, **68,** 166–81.

PATTERSON, E. M. 1950. Evidence of Fissure Eruption in the Tertiary Lava Plateau of North-East Ireland. *Geol. Mag.*, **87,** 45–52.

———. 1955a. The Tertiary Lava Succession in the Northern Part of the Antrim Plateau. *Proc. R. Irish Acad.*, B, **57,** 79–121.

———. 1955b. The Tertiary Volcanic Succession in the Western Part of the Antrim Plateau. *Proc. R. Irish Acad.*, B, **57,** 155–78.

REYNOLDS, D. L. 1940. Contact Metamorphism by a Tertiary Dyke at Waterfoot, County Antrim. *Geol. Mag.*, **77,** 461–9.

ROHLEDER, H. P. T. 1925. A Volcanic Vent in the White Rocks Quarry, Portrush. *Irish Nat. J.*, **1,** 98–100.

SYMES, E. G., F. W. EGAN & A. M'HENRY. 1888. Explanatory Memoir to accompany Sheets 7 and 8. *Mem. geol. Surv. U.K.*

TILLEY, C. E. & H. F. HARWOOD. 1931. The dolerite-chalk contact of Scawt Hill. *Miner. Mag.*, **22,** 439–68.

TOMKEIEFF, S. I. 1934. Differentiation in Basalt Lava, Island Magee. *Geol. Mag.*, **71,** 501–12.

———. 1935. The Dolerite Plug of Ballygalley Head. *Irish Nat. J.*, **5,** 252–7.

TOMKEIEFF, S. I. 1940a. The Dolerite Plugs of Tieveragh and Tievebulliagh, near Cushendall. *Geol. Mag.*, **77**, 54–64.

———. 1940b. The Basalt Lavas of the Giant's Causeway District of Northern Ireland. *Bull. volcan.*, II, **6**, 89–143.

——— & E. M. PATTERSON. 1947. The Tertiary Igneous Rocks in the Neighbourhood of Ballintoy. Part I. The Knocksoghey Sill. *Irish Nat. J.*, **9**, 89–96.

——— & ———. 1948. Part II. The Carrickarade Volcano. *Irish Nat. J.*, **9**, 203–12.

TYRRELL, G. W. 1937. Flood Basalts and Fissure-Eruption. *Bull. volcan.*, II, **1**, 94–9.

WALKER, F. 1940. Differentiation of the Palisades Diabase, New Jersey. *Bull. geol. Soc. Amer.*, **51**, 1059–1105.

WALKER, G. P. L. 1948. A Preliminary Note on the Metamorphic Rocks of the Portmuck area, Islandmagee. *Irish Nat. J.*, **9**, 165–8.

———. 1951. The Amygdale-Minerals in the Tertiary Lavas of Ireland. I. The Distribution of Chabazite Habits and Zeolites in the Garron Plateau area. *Miner. Mag.*, **29**, 773–91.

WRIGHT, W. B. 1924. The Age and Origin of the Lough Neagh Clays. *Quart. J. geol. Soc. Lond.*, **80**, 468–88.

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