The crossdoney igneous complex

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A PETROLOGICAL STUDY OF THE PORTRUSH SILL AND ITS VEINS.

BY

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Descriptions of Figures 1 - 4.

Fig. 1. Map of Portrush and The Skerries. The distribution of hornfelsed Lias is indicated by line-shading.

Fig. 2. Sketch map of Portrush, showing the localities of specimens referred to in the text.

Fig. 3. Field relations of sill, inclined sheet (Group III) and veins (Group II) near the edge of the 'Peak Pool'.

Fig. 4. Variation diagram illustrating the variation in modal composition of specimens from the cliffs of Ramore Head.

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Fig. 5. Cordierite hornfels.
Shows stumpy crystals of pleochroic cordierite (white) with inclusions of ore and pyroxene, and diopsidic augite grains (outlined and dotted) in a cloudy felsic-cordierite matrix (stippled). x .

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Fig. 8. Poikilo-plektophitic texture in No.72, developed in an inclined sheet on the edge of the 'Peak Pool'. The field shows part of a single crystal of augite (dotted) enclosing a plexus of plagioclase laths. x .

Fig. 9. Poikilo-plektophitic texture between olivine (heavily outlined) and a plexus of plagioclase laths in No.72. Poikilo-plektophitic augite is seen on the right. x .

Fig. 10. Dolerite-pegmatite, No.126. Vein in Kerr Street quarry. Prismatic grains and polysomatic aggregates of augite (outlined and dotted); plagioclase slightly replaced by calcite; and an amygdale (left centre) containing thomsonite (stippled) at the rim and chabazite centrally. x .

Fig. 11. Intergrowth of pyroxene (outlined and dotted) in plagioclase (white). No.11, vein of porphyrtie type, Portneen. The felsic mesostasis (stippled) is heavily zeolitised. x .

I. - INTRODUCTION.

Portrush, a seaport in Co. Antrim, Northern Ireland, is situated on a small promontory directed to the north-west, about five miles W.S.W. of the Giant's Causeway. The thick sill of olivine-dolerite which, with its locally preserved roof of hornfelsed Lias, is responsible for the peninsula, is continued to the north and east in a string of islands known as the Skerries (Fig.1).

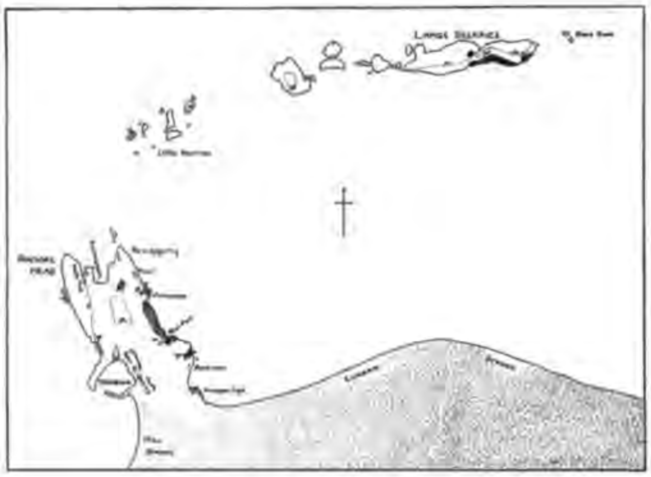

Fig. 1.

Portrush became an important centre of petrological interest when ammonites and other fossils were recognised in a rock which at that time was thought to be a variety of basalt. The exact date of the discovery of the fossils is unknown, and the earliest reference to them is recorded by Kirwan (1799, p.252). The evidence was claimed by Richardson (1803, p.481) as supporting the Neptunistic view of the origin of basalt, despite the fact that Playfair (1802, p.286) had already pointed out that the ammonites occured in 'a sort of hornstone' or 'indurated stratified stone'. The Plutonist view was later maintained by Conybeare and Buckland (1816), who showed that the fossils of the hornstone could be matched by those of the Lias near Ballintoy; and by Bryce (1835), who recognised that the intrusion lay below the hornstone. Later in 1835, the controversy was brought to an end by Griffiths in a celebrated Presidential Address to the Geological Society of Dublin (for a summary, see Portlock, 1843), in the course of which he drew attention to the important discovery that the channel floor between Portrush and the Skerries 'is composed of stiff blackish blue clay, much resembling the decomposed lias at Ballintoy'. The accumulated evidence which he summarised led him to the conclusion that the 'flint slate of Portrush and the Skerries is lias shale indurated by the action of trap in a state of fusion'.

The first mineralogical description of the rocks of the sill was given by Oldham (in Portlock, 1843, p.150), but the olivine was not then recognised. Hatch revised the petrography for the Geological Survey of Ireland (1888, p.40). The metamorphism of the roof and of intercalated sheets and xenoliths of Lias in the olivine-dolerite was studied by Lacroix (1893, p.654) Cole (1906), and Thomson (1907). The occurence of doleritic and leucocratic veins in the upper part of the sill was recorded by Geikie (1897, p.300 and Fig.317) and Cole (1906).

In the course of the present investigation the Portrush area has been mapped on the 25-inch scale. Particular attention has been paid to the variations within the sill itself, and to the various types of veins and their relationships with the hornfelsed Lias. The map, Fig.2, shows the positions of the various specimens of the hornfels, sill-rocks and veins described in the following pages. The specimens and sections cut from them are now in the collection of the Geology Department of the Durham Colleges.

Fig. 2.

II.- FIELD OBSERVATIONS.

Geological Setting.

The map, Fig.1, illustrates the setting of the Portrush sill in relation to the geology of the district. The hornfels which forms the roof of the sill was first referred to the Lower Lias by Conybeare and Buckland (1816) from the evidence of ammonite and other organic impressions, such as are found in great abundance in many of the exposures near the Blue Pool. At Ballintoy the unmetamorphosed Lower Lias is a calcareous shale rich in organic remains. At Portrush and on the Large Skerries it is represented only by flinty hornfels, often of porcellanite type, the mineralogy of which is summarised on p.25. The Chlak overlies the Lias unconformably and is well exposed in the 'White Cliffs' east of Portrush, and in a small quarry south of the town. The Chalk in turn is overlain by the Lower Plateau Basalts, the eruption of which is assigned to Lower Tertiary times.

The Portrush Sill.

Apart from local irregularities, the upper surface of the intrusion is concordant with the hornfelsed Lias. The roof-contact is well exposed along the east shore of the peninsula, at the top of the quarry in Kerr Street, and along the south shore of the Large Skerries. Alternations of thin sheets of hornfels and fine-grained olivine-dolerite characterise the east shore of Portrush and can be well seen in section at the

Blue Pool, where five alternations are visible at low water. Here the layers dip at 11° to the E.S.E., while to the north of the Blue Pool both hornfels and roof dip at 8° to the east. The relations suggest that the magma ploughed upwards into the roof and fingered off successive layers of the invaded formations. Similar features are duplicated in the Skerries exposures, where, however, the dip is 14° to the S.E. Above the cliffs of Ramore Head and those of the north side of the Large Skerries the sill rises gradually to a height of a hundred feet; in both localities the exposed rock is coarse grained, the roof having been removed by denudation. The base of the intrusion is unfortunately nowhere visible, and no estimation of the thickness is practicable. The fact that the outcrops are disposed like the rim of a spoon suggests that the intrusion may have an elongated lopolith-like form, the long axis trending W.N.W. The continuation of the intrusion to the E.S.E. is hidden by sand dunes and the sea.

Vertical jointing is well developed, mainly in N.W.- S.E. and N.E.- S.W. directions. The crude columnar structure thus produced can be plainly seen in the cliff sections. The joints locally occur in closely spaced, narrow swarms, and along these highly jointed bands, marine erosion is greatly facilitated.

Veins and Associated Sheets.

The textural and mineralogical types represented in the veins and sheets which occur in the sill are far more varied than previous records would suggest. It has been found convenient to classify the types into the following classes and groups:

A.- Veins of Hornfels.

B.- Plagioclase-Pyroxene Veins and Sheets, with or without Olivine.

  Group I.- Intergranular ('basaltic').

  Group II.- Orthophyric.

  Group III.- Poikilo-plektophitic (doleritic).

  Group IV.- Dolerite-pegmatite and Leucocratic Porphyrite.

C.- Calcite-Zeolite-Chlorite Veins.

Class A.- Veins of Hornfels. Narrow, dark-coloured, flinty-looking, vertical veins, never exceeding three-quarters of an inch in width, occur in the upper part of the sill along the east shore, particularly north and south of the Blue Pool. Many of them can be traced without a break up to contacts where they merge imperceptibly into sheets of hornfelsed Lias, of which they clearly represent a squeezed-out part. Others, no longer connected with a visible source, are seen in section to be identical with those having a Liassic source. With increasing distance from the Lias, metacrysts and glomeroporphyritic aggregates of plagioclase, augite, and even olivine, appear in the dense matrix and gradually become more conspicuous. Some of the more pyroxenic varieties develop characters which closely approach those of the intergranular 'basaltic' veins of Group I. Another, a cordierite-felsic type, is gradually transformed into a felspathic orthophyric type resembling the more leucocratic varieties of Group II. Sheets of highly felspathised hornfels, spotted with zeolite amygdales, can also be found. As these contain poikilophitic augite in all stages of development, they link on naturally to the veins of Group III.

Class B.- It is noteworthy that, although veins of hornfelsed Lias cut the igneous rock of the sill, the igneous-looking veins of Class B have nowhere been observed in the hornfelsed Lias. They are not only confined to the sill, but, with one exception (a poikilo-plektophitic olivine-bearing vein from the base of the cliffs of Ramore Head), they occur only in the immediate vicinity of the roof.

Group I.- Dark, narrow, vertical, aphanitic veins, microscopically resembling intergranular basalt, occur on Reviggerly and south of the Blue Pool. They have been found only very close to the roof, either cutting the sill rock and chilled against it, or injected into earlier pegmatitic or leucocratic veins, against which they are also 'chilled'. Some of the mobilised hornfels veins develop into types which closely resemble the members of this group, the similarity extending even to the appearance of a chilled contact.

Group II.- The orthophyric veins and sheets have a distinctive appearance both in the field and in thin section. Megascopically they might be taken for layers of ferruginous sandstone, an effect due to the development by weathering, of a thick, brown-speckled, crust. The fresh rock, sometimes difficult to collect, is dark green and fine in grain. Microscopically, the Group is distinguished by the orthophyric assemblage and more sodic character of the plagioclase, the green colour of the augite, and the abundance of serpentinous products. On Reviggerly and in Portscaddon Bay sheets and masses of irregular shape are united by oblique and vertical veins of varying thickness. The most persistent of all the veins examined - - the 'Great Vein' - - can be traced from the S.E. corner of the 'Peak Pool' on Reviggerly to Portandoo. Similar vertical veins, though shorter and thinner, occur between Portneen and the Blue Pool. Many examples of this Group form composite veins with members of the pegmatitic veins of Group IV, occuring within the latter, and locally breaking through them to continue at right angles, or thereabouts, as separate veins (see Fig.3). Near the 'Peak Pool' a member of Group II (73) occurs in and cuts through a sheet-like mass of poikilo-plektophitic olivine-dolerite of Group III (72).

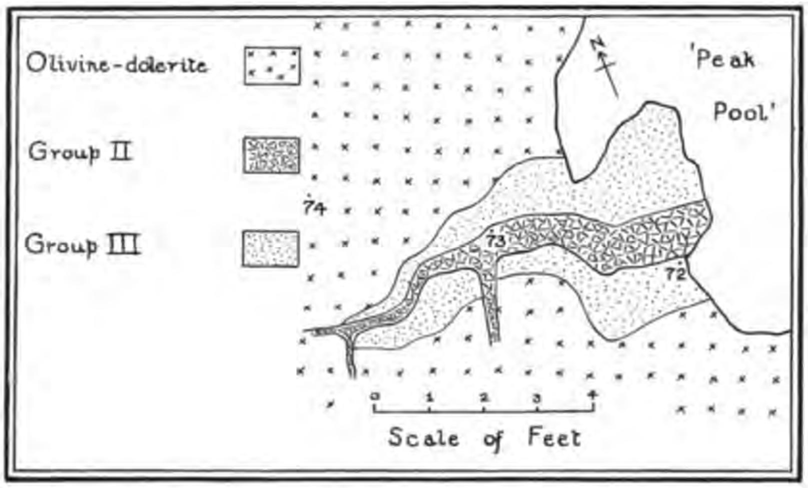

Fig. 3.

A syntectic mode of origin for the orthophyric veins is demonstrated by the fact that a typical example (153) can be traced into mobilised hornfels which emerges visibly from a sheet of Lias. This vein occurs on the rock slope due east of the Church of the Holy Trinity. It is half-an-inch wide where it leaves the hornfelsed Lias and can be followed for several feet through the marginal type of the sill in a northerly direction. Eighteen inches from its Liassic source it has already been transformed into a felspar-rich orthophyric material (see p.37).

Group III.- Grey fine-grained veins and sheets of hypersthene-dolerite and olivine-dolerite, characterised by a remarkable poikilo-plektophitic texture occur near the contact on Reviggerly. An olivine-bearing variety (26) forms a thin vertical vein which can be traced across the wave-cut platform below Ramore Head and up the cliff till it dies out at a height of about 18 feet. This vein is unique in its position so deep in the sill, being the only one of Class B found away from the vicinity of the roof. On Reviggerly, north of the Lifeboat Station, a conspicuous upstanding mass of olivine-dolerite occurs which is referred to as the 'Reviggerly Peak', or briefly as the 'Peak'. Adjoining it to the south, is a shallow rock basin containing a pool at low tide - - the 'Peak Pool' already referred to. Here, on the shelving rock slopes, a variety of sheets and veins may be studied. One of the sheets is a raft of metamorphosed hornfels and it is highly significant that in it the development of the peculiar poikilo-plektophitic texture can be clearly traced (see p.41).

Group IV.- *Dolerite-pegmatite* and *leucocratic porphyrite* occur in lenticular and irregular sheets up to two feet thick (but generally much less), lying near and roughly parallel to the roof-contact; these finger out laterally and obliquely, and in vertical exposures they are commonly found to be interconnected by vertical veins about two inches thick. Such relations are well seen in the Kerr Street and Lansdowne Crescent quarries (see Geikie, 1897, p.300, Fig.317) and in Portscaddon Bay. It is important to notice that vertical veins often rise from sheets which themselves have no visible feeders from below. In many exposures (including those of the largest of the Skerries) the vertical veins are often seen alone, but sharp turns into horizontal bands are not rare. As described by Geikie and Cole, these sheets and veins are characterised by (a) marginal segregation of the dark minerals; (b) coarse grain; and (c) complete interlocking with the enclosing rock of the sill. It is to be noted, however, that some of the veins showing marginal concentration of pyroxene have pegmatitic borders and fine-grained leucocratic interiors, while others (e.g. 13) have a pyroxene-rich margin on one side which locally traverses the vein as a definite band and becomes the margin on the other side. Moreover, examples are not lacking in which the dark minerals are uniformly distributed. It will be seen that the term dolerite-pegmatite is applicable in its common usage only to some of the veins and to the marginal parts of others. For want of a better term, the others are grouped together as leucocratic porphyrite. In all save the most highly felspathic members of the Group a pitted surface is developed by weathering, the pyroxene remaining as projections above the less resistant felsic minerals.

Class C.- Calcite-Zeolite-Chlorite Veins. These are of widespread occurrence and are as numerous at the base of the cliffs of Ramore Head and the Skerries as they are near the top of thd sill. Two well marked varieties are developed.

(a) Calcite-zeolite-chlorite veins occur in bands, up to four feet, but usually about one foot, across, and are characteristically developed on Ramore Head. They appear to be confined to the olivine-dolerite of the sill and have not been observed cutting the veins of Class B. Each vein tends to follow a vertical joint for some distance, after which it may subdivide upwards or laterally, by deviating into minor joints and cracks. The bands are eroded into chimneys in the cliff face and into long narrow clefts between tide marks. The 'Wash Tub' on the east side of Ramore Head is the most impressive example.

(b) Narrow zeolitic veinlets, often variegated with a central band of chlorite, and never more than half-an-inch wide, are found in every exposure. These, too, are roughly vertical, and can be seen to cut every other type of vein. On a microscopical scale they may be found even in the hornfels of the roof.

III.- PETROLOGY.

Pyroxenes.

As five definite types of pyroxene have been recognised in the rocks investigated, it will be convenient to summarise their properties for ease of reference and comparison.

Augite. Under this name the common greenish brown pyroxene of the olivine-dolerite will be described. Together with varieties differing only slightly in colour, it is found in many of the veins and occasionally in certain bands of the hornfels near the contact. In the marginal type of the olivine-dolerite it occurs as small grains, but in its characteristic development through the body of the sill it builds large anhedral crystals ophitically enclosing plagioclase. In many of the rocks the texture becomes poikilophitic on a spectacular scale (Plate A, Fig.1), the augite as it were forming the matrix, optically continuous over several square centimetres, to a plexus of very small plagioclase laths. Professor Holmes has suggested the provisional term poikilo-plektophitic for this texture.

Analysis of the augite separated from specimen 189, collected from the foot of the cliffs near the Harbour, gave the following results. The composition and optical properties (listed below the analysis) are very like those of the analysed augites from Etna and Stromboli (Washington and Merwin, 1921) and various Japanese basaltic rocks (Kuno and Sawatari, 1934, p.341).

Augite from olivine-dolerite, Portrush Sill.

	Percentages.	Mol.Props.
SiO_2	51.05	.8500
Al_2O_3	5.23	.0513
Fe_2O_3	.90	.0056
FeO	7.35	.1023
MgO	14.18	.3517
CaO	19.10	.3406
Na_2O	.39	.0063
K_2O	.07	.0007
H_2O+	.50	-
H_2O-	.50	-
CO_2	none	-
TiO_2	.50	.0063
P_2O_5	tr.	-
MnO	.25	.0035
	100.01	

Molecular Composition.			
Diopside	$CaSiO_3$	30.42	56.71
	$MgSiO_3$	26.29	
Hedenbergite	$CaSiO_3$	9.14	19.52
	$FeSiO_3$	10.38	
Hypersthene	$MgSiO_3$	9.01	13.59
	$FeSiO_3$	3.58	
Acmite	$NaFeSi_2O_6$		2.59
Jadeite	$NaAlSi_2O_6$		.28
	$KAlSi_2O_6$		.31
	$AlAlO_3$		5.09
Excess	SiO_2		1.43
	TiO_2		.50
			99.02
Water			1.00
			100.02

Analyst - W.H.Herdsman.

Pleochroism: X=Y= Brownish; Z= Greenish Brown.

2V= ca 58°. $Z_{\wedge}c$= 40°.

Green Augite occurs as anhedral grains of varied size in the orthophyric veins of Group II. Pleochroism: X=Y= pale green; Z= darker green. 2V is about 60 , Z c= 50 . It is frequently rimmed with aegerine-augite of deeper colour and stronger pleochroism in which Z c rises to 60 . Jennings (1899) has already recorded a soda-pyroxene from a vein in the Portrush sill. That the green augite is probably richer in soda than the normal augite is further indicated by its constant association with plagioclase zoned from andesine to oligoclase and with thomsonite to the exclusion of chabazite.

Pigeonite occurs in some of the veins of Group IV, either alone or in polysomatic aggregates with augite. From the latter, however, it may be distinguished by its smaller optic axial angle. Analysis of the pigeonite from specimen 69, representing a vein in the Lansdowne Crescent quarry, gave the results listed below. The mineral differs from average pigeonite (Barth, 1931, p.196) in its relatively high proportion of ferrosilite, a character it shares with the hypersthene next to be described.

Pigeonite from doleritic vein in Portrush Sill.

	Percentages.	Mol.Props.
SiO_2	50.15	.8350
Al_2O_3	1.95	.0191
Fe_2O_3	2.15	.0135
FeO	17.22	.2397
MgO	13.08	.3244
CaO	11.02	.1965
Na_2O	.38	.0061
K_2O	.12	.0013
H_2O +	.60	-
H_2O −	.40	-
CO_2	none	-
TiO_2	2.40	.0300
P_2O_5	tr.	-
MnO	.65	.0092
	100.12	

Molecular Composition.			
Diopside	$CaSiO_3$	12.42	23.15
	$MgSiO_3$	10.73	
Hedenbergite	$CaSiO_3$	10.41	22.23
	$FeSiO_3$	11.82	
Hypersthene	$MgSiO_3$	21.83	42.86
	$FeSiO_3$	21.03	
Acmite	$NaFeSi_2O_6$		2.82
	$KAlSi_2O_6$		.57
	$AlAlO_3$		1.81
	$FeFeO_3$		.98
Excess	SiO_2		2.14
	TiO_2		2.40
			98.96
Water			1.00
			99.96

Analyst - W.H.Herdsman.

Pleochroism: slight in tints of pale brown or pale green.

$2V = 38^\circ$. $Z \wedge c = 45^\circ$. $\gamma - \alpha = .022$ (Berek compensator).

Hypersthene occurs in some of the leucocratic porphyrite veins of Group IV as tabular prismatic crystals up to 7 mm. long, though generally much smaller. It is associated with augite and sometimes with an iron-rich olivine, in consequence of which efforts to separate it for analysis proved unsuccessful. The optical properties, however, permit a close estimate to be made of its composition (specimen 60). Pleochroism: X= pale reddish brown; Y= yellowish to pinkish; Z= pale green or bluish green. 2V, between 52° and 54°. $\gamma - \alpha = .015$ (Berek compensator). Comparison with the data collected by Henry (1935, p.223) indicates a composition of approximately $En_{48}Of_{52}$. The hypersthene described by Lacroix (1904, p.506) from the andesite of Mte. Pelée is practically identical. It has been noted that some examples of the Portrush hypersthene have $Z_{\wedge}c$ up to 4°; this abnormality is not unusual but its significance does not appear to have been investigated.

A similar iron-rich hypersthene occurs in two of the syntectic veins of Group III. Here its development is poikilophitic and poikilo-plektophitic like that of the associated augite.

Diopside. Under this name, for brevity, will be described the typical diopsidic pyroxene of the hornfels. It ranges in size from minute pale green granules to stumpy prisms, .15 mm. long, which exhibit sieve texture and have a characteristic pencil-grey colour. Pleochroism is negligible. 2V is about 58° to 60°. $Z_{\wedge}c = 42°$. There appears to be every gradation between the diopsidic type and the other three types of clino-pyroxene.

Olivine-dolerite of the sill.

The bulk of the intrusion, down to the lowest level exposed, is made up of coarsely mottled ophitic olivine-dolerites Towards the roof the rock rapidly passes into a marginal type (up to about three feet in thickness) characterised by a much finer grain and an intergranular texture. This in turn rapidly passes into a dense melanocratic contact type, the grain of which is extremely fine. Contact with the hornfels is megascopically sharp, but in thin section the junction is seen to be broken by irregular tongues and streaked-out inclusions of hornfels which have in some places become relatively enriched in pyroxene and plagioclase. As Cole remarks (1906, p.62), the two rocks appear to have 'run into' one another.

The coarsely crystalline appearance of the mottled olivine-dolerite is due to the presence of greyish ophitic aggregates, up to 3 cm. across, set in a darker, but actually more leucocratic matrix. The augite of each aggregate is generally a single, anhedral crystal enclosing stout laths of plagioclase (.25 - .5mm long) in normal ophitic or poikilophitic fashion (Plate A, Fig.1) or, more commonly, enclosing large numbers of highly irregular areas each of which is made up of a plexus of very small plagioclase laths (.1 mm. or less). The resulting texture (Plate A, Fig.2), which may be distinguished by the term poikilo-plektophitic, appears to be more characteristic of metamorphic or metasomatised rocks than of normal igneous rocks, and its widespread occurence in the sill presents a particularly baffling problem. Rounded crystals of olivine are enclosed in many of the aggregates, and similar crystals occur partly within, or just outside, the margins of the aggregates. The matrix is a plexus of tiny plagioclase laths (like that enclosed in many of the augites) with interstitial thomsonite and serpentinous material, variegated by small crystals or subophitic patches of augite and an occasional olivine. It is noteworthy that the grain-size of the plexus, whether in the matrix or enclosed in augite, does not become coarser with depth.

The olivine is a colourless negative variety with 2V about 85°, properties indicating a content of about 25-30 per cent of fayalite. Early crystallisation of olivine is indicated by the composition of small plagioclase inclusions, near An_{64}. All gradations are represented from fresh to completely altered olivine, the serpentinous products being brown bowlingite and a green variety which is probably also bowlingite, but in a lower state of oxidation. Both types, singly and together, occur as pseudomorphs after olivine in the more altered varieties of the rock, and confused mixtures of the two are found in all specimens, distributed interstitially and in scattered patches.

The characteristic greenish brown augite of the rock has already been described and its chemical composition recorded (p.13). It contains inclusions of titaniferous magnetite in irregular grains varying in diameter from .1 to 1 mm.

The felspar of the ophitic aggregates is zoned from labradorite, An_{65}, to oligoclase-andesine, An_{30}, while that of the matrix is slightly more albitic, being zoned from An_{60} to An_{25}. Two easily distinguished zeolites are present: fibrous, colourless to cloudy-brown thomsonite; and non-fibrous, colourless chabazite. Of these, thomsonite is the more abundant and conspicuous. It occurs (a) as a replacement of the more calcic zones of the felspars; (b) as interstitial wedges in the matrix: and (c) as radiating aggregates bordering amygdales, of which the interiors are filled with chabazite. Calcite is also present in some of the amygdales. The two zeolites closely resemble the thomsonite and chabazite described and analysed by Tomkeieff (1934, p.503) from one of the Lower Plateau Basalts of Island Magee. For other data on Antrim thomsonite see Hey, 1932, pp.54 and 58.

In order to discriminate between plagioclase and zeolites, sections of specimens from the top and bottom of Ramore Head were stained. It was found on measurement that the ratio of plagioclase to zeolites remains almost constant.

	Plagioclase	Zeolites	$\frac{\text{Plagioclase}}{\text{Zeolites}}$
Top of Ramore Head	57.0	6.7	8.5
Foot of cliffs	35.5	4.3	8.3

The only accessory besides titaniferous magnetite is apatite, which occurs in needles (up to .05 mm. long) among the felspars and zeolites of the matrix.

In the Marginal type (Plate A, Fig.3) the texture is dominated by blades of labradorite (up to .3 mm.), An_{62}, with only slight zoning, which are commonly arranged in sub-radial groupings. Between the diverging blades granular augite, magnetite grains, olivine with occasional rims of bowlingite, and interstitial thomsonite occur. The type maintains a general uniformity of composition and texture throughout the mainland and Skerries exposures, the only significant variation found being the development of a little biotite against olivine crystals in a specimen from the Lansdowne Crescent quarry (64). Transition to the mottled type takes place by the gradual incoming of glomeroporphyritic ophitic aggregates of augite and plagioclase.

The <u>contact type</u> contains sparsely scattered laths (.2 mm) of labradorite, An_{68}, in a dense matrix which resolves under high power into granular specks of augite, olivine and black ore in an open network of felspar needles. The rock is melanocratic relative to the bulk of the sill. Very little olivine can be detected, but the grain is so fine that exact discrimination of the mafic minerals is difficult. The type bears a close resemblance to the chilled margins of the syntectic intergranular veins of Group I and, as Cole and others have already suggested, it is likely that the contact type has been modified by reaction with hornfels.

Modal Composition and Variation with Depth.

Micrometric analyses made on the Shand stage gave the following results, 1 - 6.

Minerals	Marginal Type		Mottled Ol.-dolerite			Matrix
	1	2	3	4	5	6
Plagioclase and Zeolites	39.7	40.6	63.7	44.7	37.6	84.5
Augite.	33.0	32.5	26.9	37.6	32.8	15.5
Olivine and Bowlingite	23.0	20.0	7.4	14.7	25.2	--
Titaniferous Magnetite	3.1	3.9	1.4	3.0	3.7	--
	98.8	96.0	99.4	100.0	99.3	100.0
Specific Gravity	2.92	2.92	2.84	2.85	2.92	--

1.- Average of three specimens of the marginal type from Kerr Street quarry (122); Portandoo Harbour (152); and south of the Blue Pool (162).

2.- Marginal type (analysed specimen) from Kerr Street quarry (122).

3.- Average of three specimens of the mottled type from Ramore Head, 90 to 95 feet above sea-level (184, 185 and 186).

4.- Mottled type from Ramore Head, 50 feet above sea-level (183)

5.- Average of four specimens of the mottled type from the platform at the foot of the cliffs between the Harbour and Ramore Head (182, 187, 188 and 189).

6.- Average composition of the matrix of the mottled type, omitting olivine (182, 183, 184, 185, 189 and 190).

It will be seen that, in the rocks from the Ramore Head cliffs, olivine and ore increase with depth, while the felsic minerals decrease. The variation is graphically displayed in Fig.4. Although the numerical data are not inconsistent with the idea that, relative to augite, sinking of olivine and rising

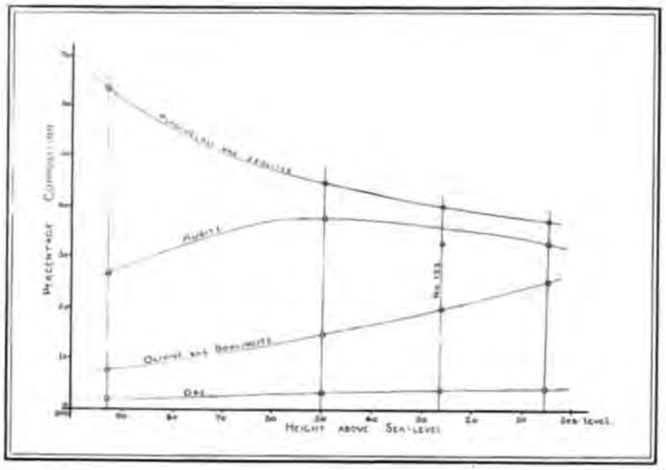

Fig. 4.

of plagioclase may have taken place, the astonishingly fine-grain of the plagioclase, even in the heart of the sill, points to a degree of viscosity highly unfavourable to the differential movements of solid and liquid phases under gravity. The poikilo-plektophitic texture might be held to imply that at the stage when the large augite crystals were beginning to consolidate, the residual liquid must have been itself almost of augitic composition (cf. Krokström, 1933, p.199). But no such inference can be safely drawn. The description of the progressive metasomatism of a sheet of hornfelsed Lias on p.41 makes it clear that the poikilo-plektophitic augite can begin to develop in an essentially solid medium even before plagioclase has become individualised. This observation further supports the view that the chief minerals of the sill crystallised under conditions of abnormally high viscosity. The evidence so far available leaves the problem of mineral composition still unsolved.

Chemical Composition.

As the uniform contact type seems most likely to approximate to the composition of the original magma, specimen 122 was chosen for analysis. The mode of 122 (see column 2 of the above Table) is plotted on Fig.4 at the level where it most closely fits the curves. The agreement indicates that 122 represents a possible mottled type.

The results of the analysis show that the rock is a representative of the Hebridean Plateau Magma-Type. This is clearly demonstrated by the comparison of the analysis (A) with the composition of olivine-basalts of this Type from Island Magee (B), Morven (C), and Iceland (D). The probability that the sill is co-magmatic with the Lower Plateau olivine-basalts of Antrim is supported not only by the close resemblance between (A) and (B), but also by the occurrence in the sill of the two common zeolites of the Lower Plateau lavas. Relatively low soda and the absence of analcite distinguish the rock from crinanite (E). An analysis of the most familiar example of the Upper Plateau basalts - - that of the Giant's Causeway - - is added (F). The latter is a representative of the Non-Porphyritic Central Magma-Type of the Survey (Tholeiitic Magma-Type of Kennedy), the average of which as computed by Tyrrell, is given in column 6.

In detail the Portrush olivine-dolerite is notable for its

Olivine-dolerite, (No. 122) Portrush Sill, Co. Antrim.

	Percentages.	Mol.Props.
SiO_2	46.51	.7744
Al_2O_3	15.60	.1530
Fe_2O_3	.99	.0062
FeO	9.14	.1304
MgO	9.05	.2245
CaO	11.77	.2104
Na_2O	1.89	.0305
K_2O	.72	.0076
H_2O+	1.79	-
H_2O-	.75	-
CO_2	.07	.0016
TiO_2	.84	.0106
P_2O_5	.52	.0037
F	.04	.0021
Cl	.04	.0011
S	.15	.0047
Cr_2O_3	.02	.0001
V_2O_3	.02	.0001
NiO	.07	.0009
CuO	.15	.0019
MnO	.16	.0023
SrO	.02	.0002
BaO	.04	.0003
	100.35	
Less O	.10	
	100.25	

Norm.			
Orthoclase			4.23
Albite			15.78
Anorthite			32.10
Halite			.05
Diopside	$CaSiO_3$	9.48	18.57
	$MgSiO_3$	5.33	
	$FeSiO_3$	3.76	
Hypersthene	$MgSiO_3$	3.26	5.46
	$FeSiO_3$	2.20	
Olivine	Mg_2SiO_4	9.77	17.02
	Fe_2SiO_4	7.25	
Magnetite			1.46
Ilmenite			1.59
Pyrite			.28
Apatite			1.24
Calcite			.16
			97.94
Water			2.54
			100.48

Auvernose (III, 5,4,4)

For mode of No.122 see p.21.

Analysed by Messrs. Imperial Chemical Industries (Fertilizer & Synthetic Products) Ltd., Research Dept., Billingham, Co. Durham.

relatively high CaO and P_2O_5 and low TiO_2. The unusual abundance of copper and nickel is og geochemical interest. These elements are probably present as sulphide or in the mafic minerals. No trace of either could be found in the zeolites. Though the amounts of BaO and SrO are about normal for basaltic rocks, it may be noted that these constituents are not usually present in more than traces in most British examples of the Plateau Magma-Type.

Contact Metamorphism.

The commonest type of hornfels is a dense finely granular rock composed of minute grains or prismoids of diopsidic augite and specks or twig-like growths of black ore, in a cloudy base consisting largely of cordierite and partly of indeterminable felsic material. Streaks of quartz appear in many of the bands, and, where the grain locally becomes coarser, small patches of quartz and plagioclase can be recognised. Individual bands, of which several may be recognised in some of the thin sections, vary considerably in grain and in the proportions of the component minerals. Chlorite and thomsonite have been introduced in veinlets which locally swell into streaks and patches.

Cordierite occurs in vaguely outlined forms crowded with inclusions; in rounded individuals, which may be clear or partly replaced by thomsonite and chlorite; and, less commonly, in ore-rimmed prismatic forms which are conspicuously pleochroic and contain inclusions of ore-grains and diopside prismoids (Fig. 5).

	A	B	C	D	E	F	G
SiO_2	46.51	46.12	45.52	47.27	47.83	50.36	50.5
Al_2O_3	15.60	15.46	14.30	14.44	15.31	14.51	13.7
Fe_2O_3	.99	3.85	3.43	.97	1.15	2.61	3.8
FeO	9.14	6.51	9.00	10.15	9.22	8.09	9.2
MgO	9.05	10.12	10.65	10.30	6.60	6.26	5.2
CaO	11.77	10.66	9.54	11.73	12.38	10.77	9.7
Na_2O	1.89	1.48	2.21	1.86	2.53	2.48	2.8
K_2O	.72	.65	.42	.18	.40	.99	1.1
H_2O+	1.79	2.38	1.53	.33	1.28	1.10	2.2
H_2O-	.75	1.01	.70	.09	.28	1.27	
CO_2	.07	-	.15	none	.05	.10	-
TiO_2	.84	1.37	2.85	2.36	2.86	1.06	1.8
P_2O_5	.52	.08	.23	.12	.16	.45	.3
F	.04	-	-	-	-	-	-
Cl	.04	-	-	.01	.01	-	-
Cr_2O_3	.02	-	-	.04	-	-	-
S	.15	trace	nt.fd.	none	-	.06	-
V_2O_3	.02	-	-	.07	-	-	-
NiO	.07	-	-	.01	.02	.02	-
CuO	.15	-	-	-	-	-	-
MnO	.16	.21	.19	.19	.36	.12	.3
SrO	.02	-	-	none	-	-	-
BaO	.04	-	-	none	nt.fd.	-	-
	100.35	99.88	100.72	100.12	100.44	100.29	100.6

A.- Olivine-dolerite, Portrush Sill, Analyst, Messrs. I.C.I. Research Department.

B.- Olivine-basalt, Middle part of flow belonging to the Lower Plateau group, The Gobbins, Island Magee, Co. Antrim. Analyst, S.I.Tomkeieff (1934, p.502).

C.- Lava of Plateau Magma-Type, east side of Rudha Dearg, Morven. Analyst, F.R.Ennos (Mull Memoir, 1924, p.15, An.III).

D.- Olivine-basalt, Grundafjord, Iceland. Analyst, H.F.Harwood (A.Holmes and H.F.Harwood, Min.Mag., xviii, 1918, p.196).

E.- Crinanite, southern face of Garbh Eilean, Shiant Isles. Analyst, E.G.Radley (F.Walker, Q.J.G.S., lxxxvi, 1930, p.371). For other analyses and an average, see F.Walker, Geol.Mag., 1934, p.126.

F.- Basalt, Upper Plateau group, Giant's Causeway, CO. Antrim. Analyst, Messrs. I.C.I. Research Department.

G.- Average of 8 analyses of British rocks representing the Tholeiitic Magma-Type (G.W.Tyrrell and K.S.Sandford, Proc. Roy. Soc. Edin., liii, 1933, p.312, No.8).

In specimen 74, from a raft of hornfels exposed in a rock-slope N.W. of the 'Peak', cloudy cordierite occurs in irregular crystals up to 8 mm. across, which are variegated with black ore and an unidentified mineral, and separated from each other by bands of fibrous pale-green chlorite (Fig.6). A few aggregates of labradorite are present, also crowded with inclusions of ore. Clear, rounded areas are present in the cloudy crystals, with which they are optically continuous, and almost every example has a core of spherulitic chlorite. The unknown mineral occurs as narrow highly birefringent laths which are pleochroic in shades of violet. The crystallographic ahd optical properties are like those of dumortierite except that the elongation is positive instead of negative.

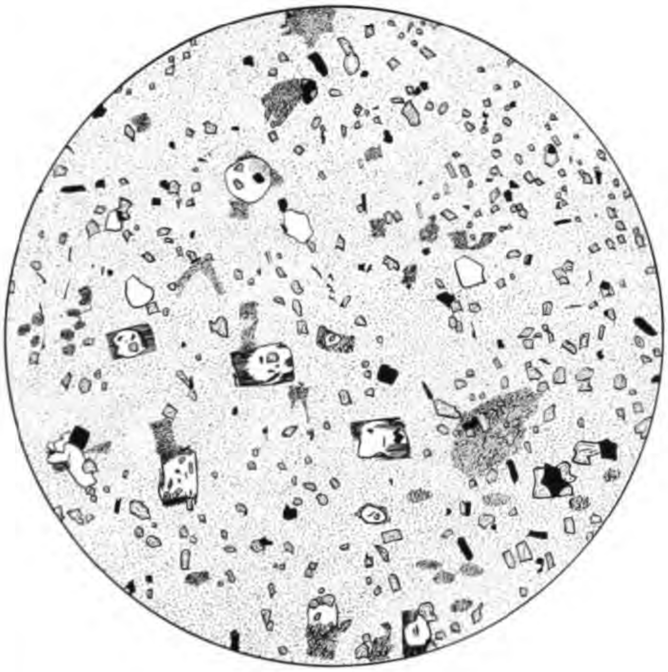

Fig. 5.

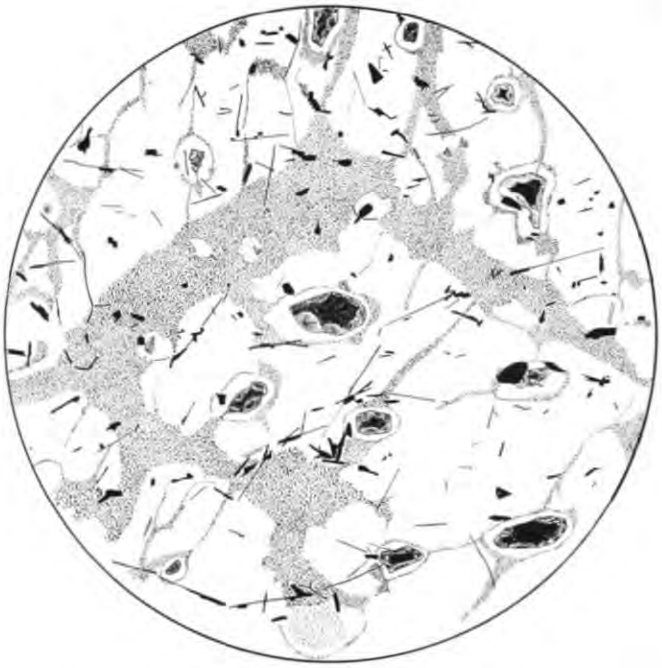

Fig. 6.

The typical mode of occurrence of diopsidic augite has already been described. In certain bands, grains, poikilophitic patches and discrete crystals of darker augite appear, ranging in colour to green, brownish or fawn. The gradation appears to be towards pigeonite and the common augite of the sill rock. The grains are often closely packed and, as interpreted by Cole (1906, p.59), they sometimes appear to represent replacements of fossils. The occurrence in layers near the roof-contact of larger grains of brownish augite, often associated with labradorite, suggests recrystallisation under the influence of magmatic emanations, particularly as small nests or amygdales of thomsonite also appear near the contact. It is noteworthy that Oldham (in Portlock, 1843, p.150) recorded the occurrence in cherty hornfels of a small belemnite 'the cavity of which is filled with the crystalline augite rock that underlies'*.

Biotite develops later than the pyroxene grains, which it encloses poikilitically. It occurs both in ragged flakes and in groups of long (20 mm) parallel or divergent laths, each group having a common optical orientation but crossing other groups at high angles. As noted by Cole, biotite is only seen near the contact. However, within the biotite-zone, biotite itself is restricted to particular bands and does not systematically increase either in size or abundance as the olivine-dolerite is approached. It seems likely that the biotite bands represent sericite-bearing layers of the original sediment.

The biotite-free assemblages of minerals can all be

*(i.e. the dolerite).

regarded as metamorphic derivatives from layers of sediment made up of the following minerals in varying proportions:

Sediment.		Hornfels.	
Clay minerals	($H_4Al_2Si_2O_9$)	Anorthite	($CaAl_2Si_2O_8$)
Chlorite	($H_8Mg_5Al_2Si_3O_{18}$)	Cordierite	($Mg_2Al_4Si_5O_8$)
Calcite		Diopside	($CaMgSi_2O_6$)
Quartz		Quartz	
Iron ores		Magnetite	

Adopting the above simplified formula (iron associated with Mg and Al being omitted), the following equations, on both sides of which additional iron ore and quartz may be placed, suggest some of the possible changes.*

Clay + Calcite = Anorthite + 2 H_2O + CO_2

8 Clay + 2 Chlorite + 3 Quartz = 5 Cordierite + 24 H_2O

Clay + Chlorite + 6 Quartz + Calcite = Cordierite + 3 Diopside + 6 H_2O + 3 CO_2

Chlorite + 9 Quartz + 6 Calcite = 5 Diopside + Anorthite + 4 H_2O + 6 CO_2

The fact that labradorite, or a more sodic plagioclase, appears in place of anorthite indicates that soda was available, as an original constituent of the sediment or as a magmatic introduction.

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* See A.Brammall, Science Progress, No.120, 1936, Fig.1, for a triangular diagram which is of great value in suggesting the detail of these and a wide variety of other possible mineral transformations.

Veins of Mobilised Hornfels.

Several occurrences have been found of veins of hornfels which differ in no essential respect from common cordierite-diopside-ore type, except that a marked taxitic structure is locally developed as a result of irregular streaking roughly parallel to the walls. Some of these veins are in visible connection with the hornfelsed Lias from which they issue.

No.208, representing a vein which passes downwards into the sill from an outcrop of hornfels south of the Lifeboat Station, Portandoo, has tiny grains of greenish diopside and black ore in a cloudy to colourless base which locally coarsens to recognisable patches of cordierite and plagioclase, the latter being rare. Here and there radiating aggregates of zeolite break the matrix and relatively coarsely crystalline lenses occur of the hornfels minerals, together with interstitial zeolite. There is marked evidence of differential movement, streaks of the more leucocratic material having been squeezed into the more pyroxenic parts.

No.210, from the shore rocks south of Portandoo, is internally essentially of the above type, but is noteworthy in having coarsely crystalline leucocratic borders of cordierite associated with euhedral prisms of plagioclase (3 mm. long) both minerals being crowded with minute inclusions. Diopside grains, stumpy prisms of pale-greenish brown augite, and sub-hedral grains of ore are sparsely distributed. The interior has strings of similar augite in rounded grains of much larger size than those of the hornfelsic matrix. Angular patches of zeolites are more abundant than usual. Certain veins from the Lansdowne Crescent quarry show similar characters more conspicuously developed. The cordierite of the interior has locally cleared into limpid oval patches with augite inclusions or central nests of thomsonite. The marginal zone is mainly composed of large cordierite crystals showing sector twinning and containing only a few grains of augite.

The above veins probably illustrate early stages of metasomatism but the effects are less significant than those in certain other veins and sheets, which, while clearly of hornfelsic derivation, have characters identical with those of some of the more igneous-looking veins. Such metasomatised veins and sheets will be described below in connection with the members of the Groups that they most closely resemble.

Metasomatised Hornfels and Intergranular Veins (Group I).

No.207, a narrow vein close to 210 and traced to a source in the same outcrop of hornfels, is remarkable in illustrating the growth in a typical hornfelsic matrix of all the characteristic basaltic minerals. Very minute needles of plagioclase appear among the tiny granules of pyroxene and ore, the background to these minerals being cloudy and indeterminable. Here and there lie narrow laths of labradorite (up to .5 mm. long), singly or in sub-radial and trellis-like groupings. With the latter small grains of augite are sometimes associated. Olivine is also present, generally enclosing plagioclase. An aggregate of three olivine crystals with plagioclase inclusions is shown in Plate A, Fig.4. The larger crystals appear to have existed in the vein material before the latter came to rest, since the laths are aligned with the walls and their sizes are independent of distance from the walls. The matrix, however, shows 'chilling' against the enclosing olivine-dolerite.

No.140, a vein occurring between the Blue Pool and Portneen Harbour, has a higher proportion of plagioclase laths (.05 - .1 mm. long) in a matrix which is otherwise of pyroxene-rich hornfel type. Trellis-like clusters of plagioclase, zoned from labradorite to oligoclase, are very conspicuous, the laths being up to 3 mm. in lenght (Plate B, Fig.1). Crowded granules of augite, of larger size than those of the matrix, occur between and adjacent to the laths. Metacrysts of brown to fawn augite are attached to some of the laths, but are rare in this rock. Blebs of serpentine,some of which have cores of clear olivine, are sparsely distributed.

No.145 is a vein occurring near 140, which it closely resembles, except for a relatively abundant development of metacrysts of augite. The latter are in long prismatic forms (2 - 4 mm.), often perfectly euhedral, occurring alone or clustered with plagioclase laths. The most peculiar feature of the rock is the presence of sharply defined glomeroporphyritic aggregates of sub-ophitic augite and plagioclase (Plate B, Fig.2). Irregular grains of ore are abundant, but olivine has not been observed. The vein is traversed by narrow channels in which the minerals are those of the matrix, but of coarser grain. These locally swell out and enclose isolated metacrysts of augite and plagioclase.

No.33 is the internal part of a composite vein occurring just south of the Blue Pool. It is dense and melanocratic and is margined by leucocratic material (34) belonging to the porphyrite type of Group IV. In section the dark interior is seen to be markedly taxitic in structure, bands and inclusions of highly pyroxenic hornfels alternating with, or gradually merging into intergranular basalt, rich in augite grains and black ore, but, for a basalt, relatively poor in plagioclase. These layers closely resemble beerbachite, except that the plagioclase occurs in laths instead of in mosaic-like grains. Sub-ophitic aggregates of augite and plagioclase occur as glomeroporphyritic units, as in 145, but a noteworthy difference in that the plagioclase is An_{45} to An_{25}. Oval or circular patches of thomsonite occur in the 'basaltic' layers. The basalt of Chamarelle (Ardèche) contains small calcareous inclusions which have been metamorphosed into an augite-anorthite hornfels (with thomsonite) of somewhat similar texture (Lacroix, 1893, p.151 and Fig.11).

No.47 occurs near the 'Peak Pool' and, like 33, it is the interior of a composite vein, the margins of which are of dolerite-pegmatite (see 48 ander Group IV), against which it becomes very fine in grain. It is largely made up of material like the 'basaltic' bands of 33, but with the addition of rounded crystals of olivine associated with patches and trellis-like groups of plagioclase (Plate B, Fig.3). It is the most "igneous-looking" of all the veins of this Group, but the textures are not quite like those characteristic of igneous rocks. The olivine is an iron-rich variety, the optical properties of which correspond to the presence of about 30 per cent of fayalite. Small granules of olivine in optical continuity with their larger neighbours arenumerous as satellites of the olivine metacrysts. The minerals show no magmatic sequence of crystallisation, since augite and olivine both enclose plagioclase and are enclosed by it. As in 33, the plagioclase is zoned from andesine to oligoclase.

Origin of the Intergranular Veins.

It will be clear from the above descriptions that the veins of Group I are of syntectic origin, their material being metasomatised hornfels of an initially pyroxene-rich type. Of the hornfels minerals - - diopside, plagioclase, cordierite, iron ore and quartz - - cordierite may be regarded as a potential source of olivine. Since soda must be introduced among the activating emanations to make possible the appearance of a sodic plagioclase, some such transformation as the following may well have been involved.

$$\text{Cordierite} + 2\ Na_2O + 8\ SiO_2 = \text{Olivine} + 4\ \text{Albite}$$

Thomsonite and serpentine require the further addition of the constituents of water. Thus - as regards the chief constituents- the minimum metasomatic additions needed to transform a pyroxene-rich hornfels into a 'basaltic' rock are only soda and water, possibly with silica, if the original material was deficient in this constituent. It is probable that transfer of other magmatic constituents was necessary to bring about the growth of minerals which optically resemble those of the adjacent olivine-dolerite. Closely similar phenomena have been described by Campbell and Stenhouse (1907, p.131) from the calcareous sediments overlying the picrite-teschenite sill of Inchcolm. In addition to the colourless clino-pyroxene which is the chief mineral of the metamorphosed rock, there occur 'lenticular patches of a violet augite which closely resembles the augite of the teschenite'. One band in particular consists locally almost entirely of this violet augite, and, moreover, it merges 'into a band which in several ways recalls the fine-grained parts of the teschenite'.

Metasomatised Hornfels and Orthophyric Veins and Sheets (Group II)

No.153, a narrow vein described on p.9, clearly demonstrates the passage of mobilised hornfels into a highly felspathic orthophyric type. 153 A, collected at the point where the vein emerges from its Liassic source, differs but little from a streaky hornfels. The streakiness depends on the varying proportions of the following minerals, all of which are set in a felsic-cordierite matrix: (a) abundant tiny granules of pale green diopside; (b) magnetite in minute grains and also much larger masses, sometimes bordered with quartz; (c) minute flakes of brown biotite; (d) quartz lenticles partly replaced by calcite and chlorite; and (e) thomsonite, in the more leucocratic bands. The contact between the vein and the marginal type of olivine-dolerite in which it occurs is quite sharp for several inches. At 18 inches from the source, the vein is leucocratic and spotted, while the contact has become vague and in thin section is seen to be welded. 153 B, collected from this point, is largely composed of stumpy prisms of plagioclase near An_{35} wihh marginal zoning to oligoclase. Alteration to thomsonite in angular patches, and along a zone just within the rim, is common. Small rounded and bladed crystals of augite are distributed rather sparsely. The spotted appearance of the vein is due to the presence of inclusions of (a) fine-grained highly pyroxenic hornfels; (b) glomeroporphyritic aggregates of large grains of augite and plagioclase laths; and (c) serpentine patches associsted with magnetite. Thomsonite occurs interstitially and in small amygdales. Apatite needles occur in felspars and thomsonite. Further from the source the pyroxenic inclusions disappear and thomsonite becomes more conspicuous: interstitially and replacing the felspars, and as amygdales.

Near the 'Peak', roughly rectangular blocks are embedded in horizontal or gently sloping attitudes within the coarsely mottled olivine-dolerite. They have the sandy weathered appearance of the orthophyric veins and are heavily sprinkled with amygdales of thomsonite. But in their sudden terminations, with only slightly rounded corners, they bear no resemblance to veins.

No.206, representing one of these blocks, is found to be largely composed of stumpy prisms of plagioclase in a base of thomsonite. Indeed, texture and composition are almost identical with those of the orthophyric part of the syntectic vein, 153, the only difference being that augite is more plentiful and is the green variety that characterises all the orthophyric veins described below.

It is of interest to notice, in passing, that the same orthophyric texture, again with plagioclase ranging from andesine to oligoclase-andesine, characterises certain hybrid rocks near Ventersdorp, South Africa, (Nel, 1935, pp.99-100). These hybrids have been generated as a result of the incorporation of country rock, mainly granitic, by dolerite.

Orthophyric veins in the Portrush Sill have been found only in the immediate neighbourhood of 153 and 204. Of five veins occurring between the Blue Pool and Portneen, Nos.21 and 38 are identical with 153 B, except for the absence of pyroxenic hornfels inclusions. The spotted appearance is due to conspicuous aggregates of augite, plagioclase, serpentine and ore. No.37 is more like 206 in having more abundant green augite in irregular grains, lying between the prisms of plagioclase or partly within them. Zoning of the plagioclase is emphasised by a narrow zone of serpentine just within the rim (Plate B, Fig.4). No.146 is of the same type, though of finer grain and richer in serpentine. The latter is deep green to brown and occurs as interstitial patches as well as within the felspars. No.147 is of still finer grain and is richer not only in bowlingite-like serpentine, but also in green augite, black ore and apatite needles. In addition, it contains grains of iron-rich olivine bordered with serpentine and ore.

A vein near the 'Peak Pool', No.73, closely resembles 206, but contains more green augite and serpentine and, associated with the latter, a little interstitial quartz. This vein cuts across the poikilo-plektophitic sheet, 72 (see p.44). No.77, representing the 'Great Vein' where it first appears near the Pool, contains iron-rich olivine rimmed with serpentine as well as interstitial grains of quartz. The latter may occur very close to olivine, but it is always separated from it by serpentine. The olivine is negative; slightly pleochroic with X=Z= pale greenish yellow, Y= pale yellow; $\gamma-\alpha = .041$ (Berek compensator); and probably contains about 40 per cent fayalite. The green augite is locally in ophitic relationship with plagioclase. Despite the melanocratic character of the 'Great Vein', the plagioclase has the same composition as throughout the veins of Group II, andesine zoned to oligoclase.

No.94 is a vein from the west side of Reviggerly. It shares with 77 the association of iron-rich olivine, serpentine and quartz, but differs in that some of the green augite is enclosed in plagioclase and none of it is ophitic.

Origin of the Orthophyric Veins.

The veins of Group II together constitute a natural suite ranging from highly felspathic to iron-rich and somewhat melanocratic types. If, as seems possible, they are all metasomatised derivatives of hornfels, as one of them is proved to be, then it seems likely that the parental hornfels was in every case a cordierite-rich variety. This would readily account for the characteristic abundance of serpentine and the occasional development of olivine. The albite-rich composition of the plagioclase, the restriction of the zeolite to thomsonite, and the green augite, all alike point to soda-metasomatism. As compared with the intergranular veins, the metasomatic additions appear to have been richer in soda and possibly in silica and iron.

The highly felspathic and thomsonite-rich veins present an additional problem, since such a composition could not have been directly attained by soda-metasomatism of any of the known types of hornfels found near the sill. A possible clue is found in the presence in 153 B of inclusions of pyroxene-rich hornfels. This suggests that the metasomatised hornfels did not become equally mobile throughout, and that the felsic portions were the first to become sufficiently mobile to flow. As a result of differential syntexis and flowage, differentiation into more mobile (leucocratic) and less mobile (melanocratic) portions took place, the former advancing beyond the latter. Such a process would also account in part for the leucocratic margins of the intergranular veins already described (cf. Nos.33 and 47, p.34). The melanocratic intergranular material could then be regarded as a later derivative from highly pyroxenic material which was left behind at the time when the felspathic material, now forming the margins of these veins was squeezed into fissures in the sill.

The frequent abundance of thomsonite amygdales in the rocks of this Group, and also in some of those of the next, recalls the description by Flett (1934) of a thomsonised xenolith from the picrite-teschenite sill of Blackness. The xenolith is a calc-silicate hornfels, probably derived from the Houston Marls, and as a result of pneumatolytic processes the matrix of the rock has been replaced by thomsonite, which also occurs in spots resembling the infillings of steam cavities.

Metasomatised Hornfels and Poikilo-plektophitic Veins (Group III).

The development of the remarkable poikilo-plektophitic texture which characterises the veins of this Group can be clearly traced in a series of specimens collected from a sheet of metasomatised hornfels exposed on the edge of the 'Peak Pool'. Specimen No.201 represents the almost unaltered hornfels, which here consists of the usual felsic-cordierite background, lightly mottled with clusters of pale green pyroxene and twig-like growths of black ore. Here and there occur rounded poikilitic or poikiloblastic aggregates of magnetite sieved with plagioclase and chlorite; rounded blebs of quartz; and small amygdales of thomsonite. One side of the same specimen illustrates the transition to a felspar-rich type. Laths of plagioclase (up to .4 mm. long), zoned from andesine to oligoclase-albite, have developed in the matrix, locally forming a plexus of squat-shaped prisms with interstitial quartz and serpentine. Pyroxene has collected into more closely packed clusters and irregular grains. Black ore is similarly concentrated into discrete grains. Opaque streaks occur, within which cordierite forms clear blebs, while pyroxene remains as a cloudy dispersion; a little biotite is present in cerviform sheaves. From the outer margins of these streaks strongly zoned plagioclase grows inwards and vaguely fades off into the matrix.

No.202, from a point about 6 feet from No.201 and 18 inches from the exposed junction of the sheet with the enclosing olivine-dolerite, shows the pyroxene gathered up into aggregates of well-defined grey-green grains, large numbers of which are in optical continuity, though they appear to be separated by a fine-grained felspathic groundmass. Certain bands are rich in thomsonite stained with serpentine. In No.203 within a few inches of the contact, the augite has become much more like that of the sill, yellow green to fawn in colour and slightly pleochroic. Poikilo-plektophitic texture is well developed, the numerous grains of each poikilo-plektophitic unit being distributed through a plexus of tiny felspar laths. Granules of olivine can be detected among the augite grains. The surrounding matrix consists mainly of plagioclase laths with interstitial thomsonite. The latter also occurs in radiating globular masses from the smallest sizes up to 5 mm. in diameter. Large aggregates of plagioclase in strongly zoned prisms (3 x 2 mm.) have developed at intervals.

No.204 is like 203, but has more serpentine and ore, while poikilo-plektophitic augite, made up of irregular angular grains, extends as single optical individuals up to 3 or 4 mm. across (Fig.7).

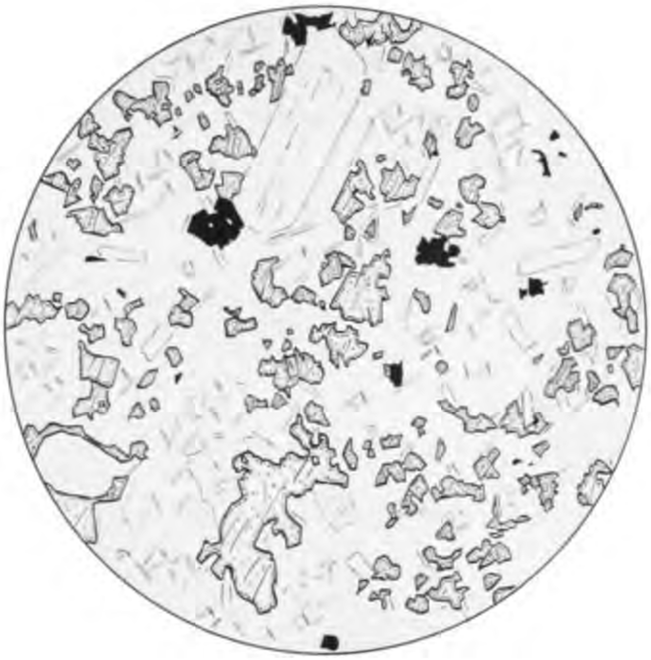

Fig. 7.

Inclusions of olivine-dolerite in the specimen, with welded contacts against the metasomatised hornfels, indicate that the latter had become sufficiently mobilised to act like an invasive magma.

In Portneen a considerable variety of veins is to be seen, (Nos.11-15), most of which are pegmatitic and leucocratic types. No.12, however, has a dark, aphanitic, hornfelsic appearance. In one section, 12A, it resembles 204, just described, but has larger areas of poikilo-plektophitic hypersthene as well as augite, and black ore is more abundant. An irregular taxitic structure is conspicuous, some bands being rich in pyroxene of considerable size which encloses in poikilo-plektophitic fashion patches of the fine-grained plexus of plagioclase laths and interstitial thomsonite which makes up the greater part of the other bands. Large metacrysts of plagioclase, zoned from An_{65} to An_{25} occur at intervals, sometimes in association with rounded masses of serpentine which enclose cores of clear olivine. Another section, 12B, shows hypersthene and augite in optically continuous arborescent growths in a plagioclase-thomsonite matrix. Granular olivine is more abundant, in slightly or considerably serpentinised masses surrounded by poikilo-plektophitic groups of augite grains.

No.93, from Reviggerly, is also very patchy in structure; it differs from 12A only in having areas of much coarser grain. In the more fine-grained poikilo-plektophitic parts hundreds of irregular pyroxene grains may form a single optical individual, of either augite or hypersthene, over areas 3 - 5 mm. across. In the coarser poikilo-plektophitic parts the augite or hypersthene remains about the same size, but each optical individual is limited to 50 grains or less, and the enclosed plagioclase laths are correspondingly larger. In this vein the chief zeolite is chabazite.

No.72 represents an inclined sheet exposed on the edge of the 'Peak Pool' (cf. No.73, p.39). It contains large poikilo-plektophitic individuals of augite and olivine, and smaller ones of black ore, all enclosing areas of the characteristically fine-grained plexus of plagioclase laths in a background of thomsonite (Fig.8 and 9). The olivine is an iron-rich type with about 25 - 30 per cent of fayalite. It is slightly altered, marginally and along cracks, to brown and green serpentine. Many of the augite crystals are in minute ragged grains, but locally these increase in size until relatively large plates are developed (up to 1 - 2 mm. across) containing only a few small laths.

No.26 is very similar, and is chiefly notable for its occurrence deep in the sill at the base of the cliffs of Ramore Head. Here the olivine has collected into more continuous oval crystals each of which has many satellite granules in optical continuity. Some of the poikilo-plektophitic areas are cloudy, as a result of zeolitic alteration of the plagioclase areas, while others contain large plagioclase laths (2 mm.) much eaten into by thomsonite. As throughout the Group, the plagioclase, whether large or small, is labradorite zoned to oligoclase.

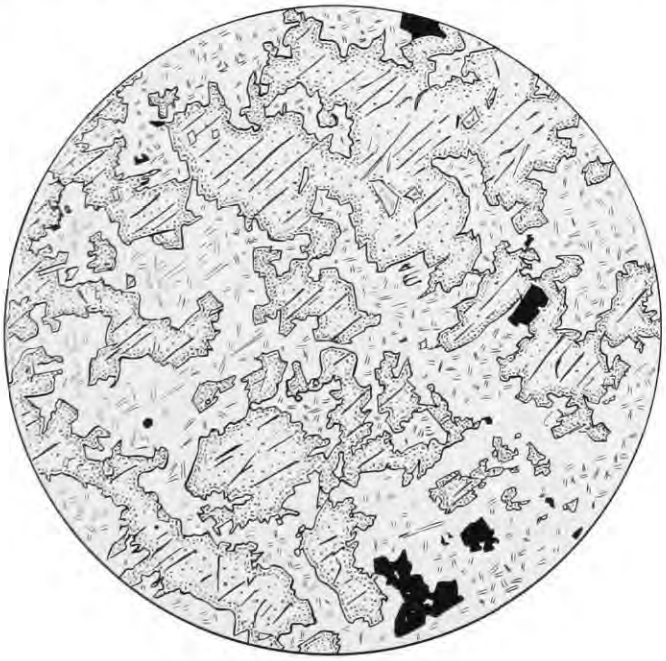

Fig. 8.

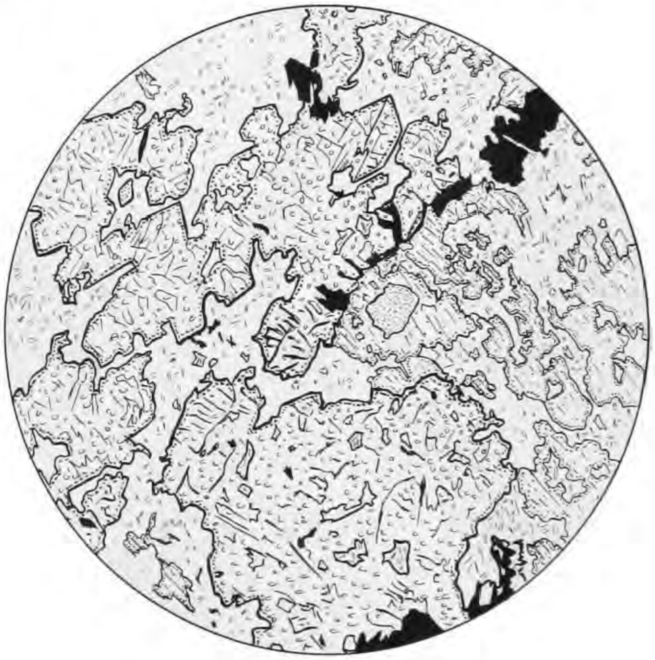

Fig. 9.

Origin of the Poikilo-plektophitic Veins and Sheets.

The striking similarity in texture - both as regards the plagioclase-zeolite plexus and the poikilo-plektophitic development of the mafic minerals - between the metasomatised hornfels of the 'Peak Pool' raft and the veins and sheets of Group III points clearly to a metasomatic-syntectic origin for the latter. The inference, however, is a far-reaching one, since in many parts of the olivine-dolerite sill itself similar textures are developed, though generally on a coarse scale which is reached only here and there in the veins. The evidence thus suggests, as a possibility worthy of further investigation, that the magma of the olivine-dolerite may have become locally contaminated by Liassic or similar lithological material to an extent that ensured development of the peculiar poikilo-plektophitic facies. Given sedimentary or hornfelsed material which can be readily metasomatised into a rock resembling dolerite, it seems likely that rocks of identical texture and analogous composition might be generated by either of two possible processes: (a) the formation of a syntectic 'dolerite' magma (not necessarily wholly fluid) by the action of highly energised emanations on the sediment or hornfels; and (b) the contamination of a dolerite magma by similar sediment or hornfels.

Before leaving this Group, it may be recalled that Thomson (1907, p.494) described a 'grey flinty type' of inclusion from the Portrush sill in terms which show beyond all doubt that it belonged to the poikilo-plektophitic group. He regarded it as a cognate xenolith. The evidence given above of the evolution of exactly similar material from hornfels, indicates that this inclusion can no longer be regarded as purely cognate. It is rather an example of the *enclaves polygènes* of Lacroix (1904, p. 537).

Pegmatitic and Leucocratic Porphyrite Veins and Sheets (Group IV).

Only a few of the specimens to be described under this heading are of the coarse-grained type of dolerite to which the term *pegmatitic* is now commonly applied. The others are more akin to leucocratic porphyrites, somewhat like the more felspathic members of the orthophyric veins, but having larger and more calcic plagioclase phenocrysts, more abundant mesostasis, and different mafic minerals. Veins of the porphyrite type commonly have margins of pegmatitic type. Throughout the Group the plagioclase is labradorite near An_{60}, zoned to oligoclase, near An_{25}. Replacement by chabazite and calcite is common along cracks and in the more calcic zones. Thomsonite is rare as a replacement, but is the dominant interstitial zeolite, varying in amount from sparse wedges in the pegmatites to a high proportion of the cloudy mesostasis in the porphyrites. Further subdivision may be conveniently based on the mafic minerals, as summarised in the following table. Black ore, sometimes with a little pyrite, is generally a conspicuous associate of the pyroxenes. Apatite in needles and stout prisms occurs in and among the felspars and occasionally in the pyroxenes, olivine and ore.

Veins and Sheets of Group IV.

No.	Locality	Augite	Pigeonite	Hypersthene	Olivine	Pegmatitic Margins
Dolerite-Pegmatites						
9	N. of Arcadia Cafe.	x				
48	Near the 'Peak'.	x				
90	N.W. of Portandoo.	x				
14	Portneen.	x				
126	Kerr Street quarry.	x				
60	Lansdowne Cres. qy.	x		x	x	
Veins of Porphyrite Type with Pigeonite						
15	Portneen.	x	x			
45	Reviggerly.	x	x			x
69	Lansdowne Cres. qy.		x			x
Veins of Porphyrite Type with Hypersthene						
106	E. end Large Skerries	x		x		x
124	Kerr Street quarry.	x		x		
11	Portneen.	x		x	x	x
13	Portneen.	x		x	x	x

Dolerite-Pegmatites.

Nos.9 and 48 contain ophitic or sub-ophitic anhedral plates of augite with which irregular masses and skeletal growths of black ore are associated. In Nos.14 and 90 only rare examples of subophitic augite occur, most of the augite being in smaller prisms and grains. No.90 is heavily replaced by zeolites, contains some interstitial serpentine, and is relatively rich in apatite. In No.126 the augite is entiraly in prisms and grains, some of which form polysomatic aggregates, while others are enclosed within the larger plagioclase crystals (Fig.10). The modal composition of 126, in volume percentages, is as follows:

Plagioclase and Zeolites	60.4
Augite	35.7
Black ores	3.9
	100.0

No.60 has fine-grained margins, rich in grains of augite, hypersthene and ore, which resemble the pyroxenic band of 13, described below. The interior of the vein, however, is coarsely crystalline, with large laths of plagioclase, locally in ophitic relationship with augite; prisms of hypersthene, some of which are intergrown with plagioclase; rounded polysomatic grains of olivine, margined with hypershtene and ore; and abundant radial aggregates of thomsonite.

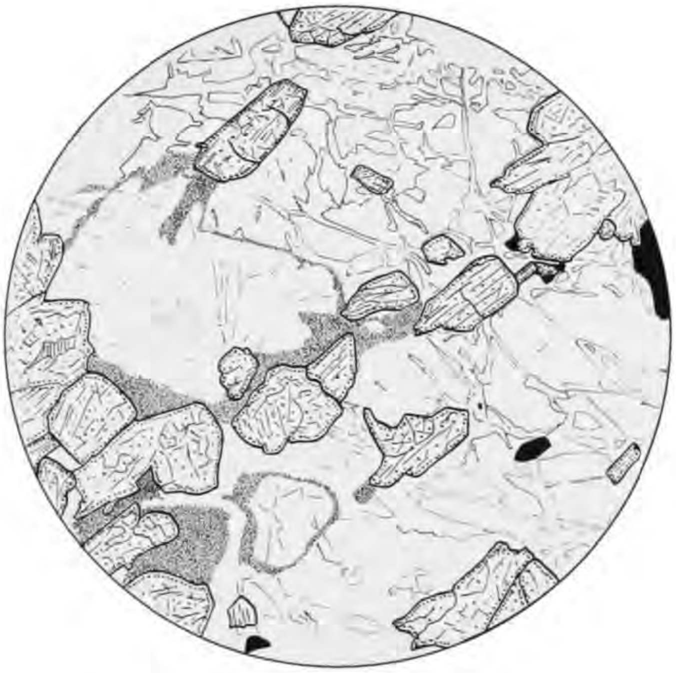

Fig. 10.

Veins of Porphyrite Type with Pigeonite.

No.15 contains pigeonite in separate grains and also, together with augite, in polysomatic groups. Plagioclase occurs in well-defined crystals in a groundmass of cloudy felspathic relics and abundant interstitial and radial thomsonite. The rock is leucocratic, as the following mode (percentages by volume) indicates:

Plagioclase and Zeolites . . .	81.0
Augite and Pigeonite	13.5
Black ore	5.6
	100.1

No.45 has pegmatitic margins with coarsely crystalline ophitic augite and ore, both minerals being much more abundant than in the interior, which is like 15, but contains less augite. No.69 has also a coarse margin, while the interior has a texture like that of the orthophyric veins. It differs, however, in the more calcic composition of the plagioclase and in the fact that the only pyroxene present is pigeonite, in discrete grains and prisms. The composition and optical properties of the pigeonite from this vein are given on p.15. A little biotite occurs against ore grains.

The structure and mineral variation of the above veins suggests that early-crystallised augite and ore became concentrated against the walls, leaving a leucocratic interior in which pigeonite became the dominant or only pyroxene.

Veins of Porphyrite Type with Hypersthene.

No.106 has well marked pegmatitic margins with long bladed prisms of augite and hypersthene. These also occur, but more sparingly, inside the vein, with large zoned plagioclase crystals, some of which contain numerous elongated grains of augite of which three or four may be in optical continuity. This is a poorly developed example of the "graphic" intergrowth described below from No.11. The felspathic mesostasis is much replaced by zeolites, and becomes more abundant towards the middle of the vein. No.124 is similar to the interior of 106, but is notable for the occurrence of a little interstitial quartz in groups of small grains.

No.11 is also generally similar to 106, but three points call for special mention. Marginal concentration of the pyroxene is very conspicuous. Olivine is an additional constituent, in grains surrounded by serpentine which in turn is sometimes in contact with quartz. Elongated grains of augite in sub-radial clusters showing optical continuity occur in some of the larger plagioclase crystals (Fig.11). In texture these are exactly like the 'micropegmatitic intergrowths between pyroxene and alkali-felspar' figured by Krokström (1936, p.178 and Fig.18) from the porphyrites which locally occupy the interior of the great Halleförs dolerite dyke.

A similar relationship between augite and plagioclase is illustrated by Teall (British Petrography, Plate 23, Fig.II) from a section of the dolerite of Hailstone Hill, Rowley, originally described and figured by Allport in 1874 (Q.J.G.S., xxx, p.549, Fig.28). Graphic intergrowth of augite and plagioclase has also been recorded from dolerite-pegmatite in Ravelrig Quarry (N.W. flank of the Pentland Hills) by Campbell and Lunn (1927, p.497 and Plate I, Fig.6). Some of the larger pyroxenes of vein No.11

are continued as a series of long parallel or forked blades into adjacent plagioclase crystals. This variety of the 'Graphic' structure has been noted by Krokström from the Halleförs porphyrites (loc.cit) and both described and figured by Lehmann (1930, p.337) from one of the Stöffel essexite dykes.

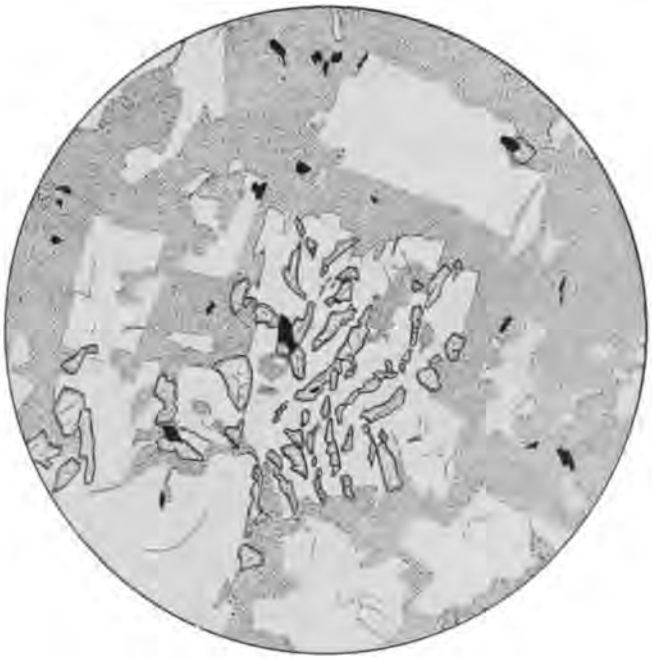

Fig. 11.

No.13 is a horizontal vein, occurring close to 11, and is remarkable for the variety and relationships of the textural types it exhibits. It has a pegmatitic margin containing augite, hypersthene and a little olivine, the augite again occurring in 'graphic' intergrowth with plagioclase. The interior is of a highly felspathic porphyrite type with some interstitial quartz but no olivine. The most remarkable feature, however, is the occurrence of a pyroxene-rich band, about a quarter of an inch wide, which undulates near one margin and crosses the vein to continue in sinuous fashion near the other margin. The band is fine;grained and contains both pyroxenes, abundant ore grains, and a little biotite, in a felspar-zeolite matrix. The junctions are merging and completely welded and give no suggestion that the band is a later injection. It seems probable that the material of this vein was heterogeneous to begin with, the different parts having had different degrees of mobility. Similar bands form the margins of the pegmatitic vein, 60, described above.

Origin of the Pegmatitic and Porphyrite Veins.

Although no direct evidence has been found relating these veins to metasomatised hornfels, there are serious objections in the way of regarding them as purely magmatic products. Objections to the hypothesis suggested by Cole (1906, p.63) that 'they doubtless represent the upwelling of the last remaining portion of the magma that underlay Portrush' are, briefly summarised, as follows.

(a) The mineral composition of the veins indicates that only olivine-free pegmatite (cf. mode of No.126 on p.49) could possibly represent a position on the 'liquid line of descent' that position being, not late magmatic, but immediatly after the crystallisation of olivine. This is established by the composition of the felspar, which ranges from An_{60} to An_{25}, and thus is practically the same as that of the plagioclase of the sill-rock. But, if the pegmatites were formed at this stage, no explanation is forthcoming for the coarse crystallisation of the felspar as compared with that of the felspar of the sill.

(b) The occurrence of such minerals as olivine, hypersthene and pigeonite in the veins.

(c) The restriction of the veins to the neighbourhood of the roof.

(d) The association of the veins with sheets of similar composition which have no visible feeders from below.

The last two objections would also apply to any postulation that the veins represent a fresh influx of magma from an external source.

It is therefore worth considering the possibility that the veins and sheets represent localised syntectic magma generated by the action of magmatic emanations from below on sheets of hornfels enclosed in the upper part of the sill. The facts favouring this hypothesis are those of (b), (c) and (d) above, together with (e) the very intimate association of the veins with others (Groups I - III) that are directly related to metasomatised hornfels. The appearance of olivine, hypersthene and pigeonite indicates abnormal enrichment in magnesia (with iron oxides) or alumina or both.

An obvious source for such enrichment is provided by the cordierite and other aluminous minerals of the hornfels, the particular mafic mineral, or combination of mafic minerals, being dependent on the relative proportions of diopside and quartz in the hornfels concerned. As regards (a) the composition of the plagioclase is consistent with a syntectic origin, since plagioclase of similar composition is generated in metasomatised hornfels. Every item of available evidence thus corresponds with the requirements of the syntectic hypothesis.

Hydrothermal Veins.

The calcite-zeolite-chlorite veins vary considerably from point to point in the relative proportions of the constituents, but calcite, often coarsely crystalline, appears to be generally the dominant mineral. It contains altered relics of augite, partly replaced by calcite or chlorite. The calcite is frequently accompanied by streaks of chabazite and of a cloudy opaque substance which has not been identified. Brownish green, slightly pleochroic chlorite also forms local streaks, and these, too, enclose partly chloritised relics of augite. Limonite appears in local bands and patches.

The later narrow veins consist mainly of thomsonite, characteristically in spherulitic development, the fibres (up to 5 mm. long) radiating out from points on the walls. The spherules interfere with one another laterally and transversely. At their margins, fibres of chlorite appear, and locally these coalesce to form a central undulating band of varying width. Only a little calcite is found.

Origin of the Hydrothermal Veins.

The age~~s~~nts responsible for these veins appear to have been essentially hydrous solutions; these were particularly rich in carbon dioxide during the formation of the veins of the earlier group. It is not clear to what extent the other constituents of the veins represent (a) residual materials left over after the consolidation of the olivine-dolerite, or (b) products of hydrothermal alteration of the original minerals of the olivine-dolerite. The presence of augite relics in the veins of the first group -- to the exclusion of other original minerals -- points to (b), as at least a contributory source. Similarly, where the later veins are seen on a microscopic scale, they appear to be channels or seams bordering cracks, along which the hydrous fluids altered the original minerals to thomsonite and chlorite. It is noteworthy, however, that the earlier veins are exceptionally rich in lime, suggesting that this constituent, at least, may have been in part a representative of (a). The later veins are relatively rich in soda. This soda might be either a complementary derivative of (b) or a final residuum of (a), or, more probably perhaps, a mixture of both. The general principles of hydrothermal metasomatism of dolerite are familiar as a result of the work of Shannon (1924, Goose Creek Diabase sill) and Wager (1929, Whin Sill, North of England).

IV.- PETROGENETIC CONSIDERATIONS.

The data assembled in the foregoing pages indicate that the veins and sheets within the olivine-dolerite of the Portrush sill include examples representing mobilised hornfels; metasomatised hornfels; types traced from the latter and others, so similar, that their syntectic origin is a reasonable inference; and finally, types (Group IV) for which a syntectic origin is inferred on evidence which, though indirect, is consistent. The hydrothermal veins can be broadly regarded as products of late residual fluids, modified by reactions with the olivine-dolerite itself. The other veins, to which attention may now be confined, appear to be mobilised and syntectic derivatives of hornfels, the activating agent being highly energised emanations.

It should not be overlooked that the mobility of the hornfels, whereby vein-injection of apparently normal hornfels became possible, cannot be ascribed to effects produced by the original magma at the time of its intrusion. This conclusion follows from the facts (a) that sharply bounded inclusions of normal hornfels occur in the upper part of the sill; and (b) that the veins occupy fissures in the enclosing sill-rock, indicating that the latter must have ~~b~~ consolidated, cooled and contracted, before the veins could be formed.

The evidence relating to the sequence of events in the upper part of the sill leads to the following succession:

1. Intrusion of olivine-dolerite magma; its consolidation and contraction to the extent required for potential fissuring.
2. Generation of the material of Groups III and IV and its injection as veins.

3a. Generation of the material of Group II and its injection through, and in some cases across, the material of Group IV. One Group II vein (72) acts similarly towards a sheet of Group III (73)

3b. Generation of the material of Group I and its injection into veins of Group IV, against which it shows chilled margins (33 into 34, and 47 into 48). Veins of Group I are themselves connected with mobilised hornfels, one example of which (153) merges directly into Group II material.

3a and 3b thus appear to have been nearly contemporaneous. If there was any interval between the two, 3b was the later, as indicated by the evidence of 153 B (p.37) that the more felspathic material of Group II became mobile before the pyroxenic material that is akin to the intergranular veins of Group I.

It is therefore clear that the activating emanations responsible for the generation of vein material were given off over a considerable period. The later emanations appear to have become richer in soda, since the plagioclase of Group II and of the two most igneous-looking veins of Group I (33 and 47) is much more albitic than that of the earlier veins of Groups III and IV. There is, however, no evidence to prove that the emanations were given off in two distinct stages. Continuous activity could still bring about the local appearance of two distinct stages. After the first injection of vein material, further generation of vein material may have been steadily progressing until the upper part of the sill (now including the earlier veins) had sufficiently contracted to permit a second injection.

The localisation and distribution of the veins call for some discussion. The absence of Veins from the hornfelsed Lias and the capacity of the latter to inject the neighbouring olivine-dolerite indicates that the hornfels was under internal tension. Beneath the vein horizon, however, the olivine-dolerite remained in a condition unfavourable to fissuring until the later hydrothermal stage was reached. Such a condition would be inevitable if the emanations were separating in a gaseous phase, for the internal pressure set up by concentration of volatiles would then be very high. Upward migration of emanations and their reactions with sheets of hornfels would lead to metasomatism and expansion of the latter, and even, if sufficient energy were liberated, to the generation of monile material and syntectic magma capable of injection into fissures made possible by the contraction of the overlying part of the olivine-dolerite. The zone of veins is thus restricted to the upper, comparatively quickly consolidated, part of the sill (i.e. between the roof and the lowest of the enclosed sheets of hornfels) because contraction of the sill-rock and expansion of the metasomatised hornfels would there most effectively co-operate to favour the production and filling of the fissures.

The only apparent exception to the application of the above hypothesis is vein 26 (Group III) from the offt of the cliffs. Since the floor of the sill is not exposed and nothing is known of the contents or extent of the sill below sea-level, no useful purpose would be served by trying to postulate conditions which would 'explain' the apparently anomalous position of this isolated vein.

There is ample evidence, recorded from many localities, of alkali metasomatism, pointing to the transfer of alkali-bearing emanations from a consolidating magma to its margins and aureole (Goldschmidt, 1922). The adinoles and other albitised rocks described by Dewey (1915), Milch (1917) and Blyth (1934), are good examples of soda-metasomatism. Describing the picrite-teschenite sill of Easter Dalmeny, Flett (1930, p.71) wrutes 'It is clear that there has been extensive migration of alkalies into the teschenite, as the felspars have been replaced by analcite through a considerable thickness of the rock. That process was pneumatolytic and was going on during the cooling of the upper layers. We are quite at liberty to suppose that at a late stage in consolidation alkali silicates were being distilled out of the centre of the sill and were being concurrently deposited in the marginal zones'. Flett has also recorded similar evidence from the Stankards sill (1932, p.153); reference to his accountof the thomsonised inclusion from the Blackness sill has already been made on p.41.

Doris Reynolds (1934, p.603) has described a spectacular example of alkali metasomatism from the eastern end of the Newry Complex, where, not only enrichment of the country rocks in biotite and plagioclase took place, but the metasomatised sediments became sufficiently mobilised to behave locally as a magma. Many other comparable examples are recorded in later contributions by Doris Reynolds (1935 and 1936) and by Holmes (1936), both of whom have directed attention to the petrogenetic significance of emanations on metamorphosed sediments and other pre-existing crustal rocks. Some of the veins and sheets of the Portrush sill constitute small-scale, but none the less striking, examples of the formation of rocks akin to dolerite and porphyrite from syntectic magmas generated by the action of emanations on hornfelsed Lias.

V.- ACKNOWLEDGMENTS.

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VII.- DESCRIPTIONS OF PLATES.

Plate A. Photomicrographs of rocks of the Portrush sill.

Fig.1. Ophitic olivine-dolerite. No.199. Lansdowne Crescent Quarry, Portrush.

Ordinary Light. x 25. See p.17.

Fig.2. Poikilo-plektophitic texture in olivine-dolerite. No.183.

The field shows part of a single crystal of augite (black) enclosing a plexus of plagioclase laths.

Nicols crossed. x 25. See p.17.

Fig.3. Marginal type of olivine-dolerite. No.122, Kerr Street Quarry, Portrush.

Showing groups of divergent plagioclase laths with granular augite, olivine and ore between the laths.

Ordinary Light. x 25. See p.19.

Fig.4. Contact between vein of metasomatised hornfels (traced from hornfelsed Lias) and the marginal type of olivine-dolerite. No.207, from the shore rocks south of Portando Portrush.

The vein contains minute needles of plagioclase and a relatively large aggregate of three crystals of olivine which contain plagioclase inclusions.

Ordinary Light. x 34. See p.32.

Plate B. Photomicrographs of vein-rocks in the Portrush sill.

Fig.1. A vein of metasomatised hornfels related to Group I, containing trellis-like clusters of plagioclase, zoned from labradorite to oligoclase. No.140 from between the Blue Pool and Portneen Harbour, Portrush.

Ordinary Light. x 31. See p.33.

Fig.2. A vein on metasomatised hornfels related to Group I, showing a glomeroporphyritic aggregate of sub-ophitic augite and plagioclase. No.145 from between the Blue Pool and Portneen Harbour, Portrush.

Ordinary Light. x 31. See p.33.

Fig.3. Intergranular vein of Group I, showing a relatively large crystal of olivine and a trellis-like grouping of plagioclase laths in a groundmass somewhat resembling intergranular basalt. Some of the granules near the large olivine are also olivine, optically continuous with the main crystal. No.47, near the 'Peak', Portrush.

Ordinary Light. x 25. See p.34.

Fig.4. Orthophyric vein of Group II. Showing stumpy prisms of plagioclase (andesine zoned to oligoclase) each of which has a serpentine zone within the rim. No.37, from between the Blue Pool and Portneen Harbour, Portrush.

Ordinary Light. x 25. See p.38.

Plate A

Fig. 1.

Fig. 2.

Fig. 3.

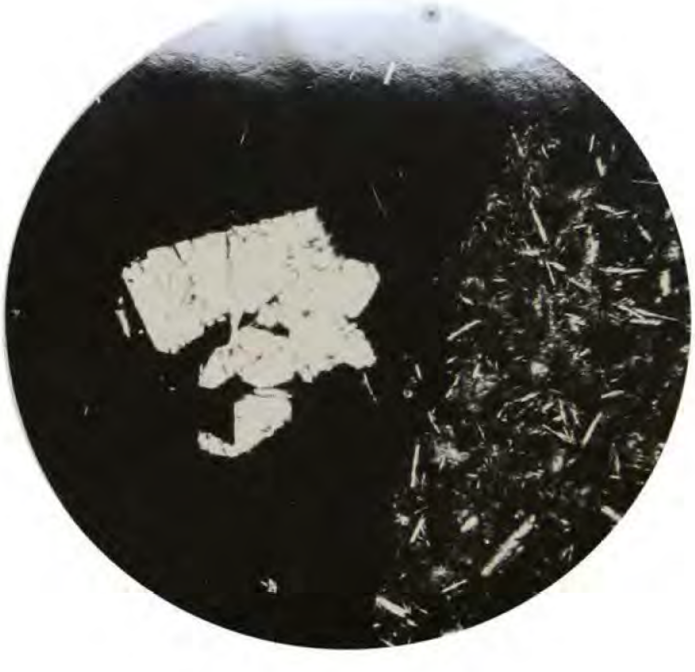

Fig. 4.

Plate B.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.