With the author's Compts.

(15)

HE DISTRIBUTION & SIGNIFICANCE F DEVIATIONS FROM THE NORMAL RDER OF CRYSTALLIZATION, ALSO HE DISTRIBUTION & SIGNIFICANCE F MICROPEGMATITE IN GRANITES, S ILLUSTRATED BY THE GRANITES OF THE NORTH OF SCOTLAND

or shortly

The Crystallization of Granites,

BY

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ETC.

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The Distribution and Significance of Deviations from the Normal Order of Crystallization, also the Distribution and Significance of Micropegmatite in Granites, as illustrated by the Granites of the North of Scotland. By WILLIAM MACKIE, M.A., M.D., &c.

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IN some of my previous investigations, which entailed the microscopic examination of a considerable number of the granites of the North of Scotland, it became evident that deviations from the normal order of crystallization existed in almost every rock-slice I examined, while the occurrence of areas of micropegmatite in the same rocks appeared to be far more frequent than the ordinary descriptions of such rocks would indicate. The present research has accordingly been undertaken with the view of testing these general impressions; to obtain data from which some generalization may be made as to the order of crystallization, and as to the occurrence and distribution of micropegmatite; and further, if possible, to arrive at some definite conclusions as to the origin and causation of the observed phenomena. In this connection specimens from most of the larger granite masses of the North of Scotland, that is from north of the Grampian range, have been subjected to microscopic examination. The rocks of the Grampian range itself are probably insufficiently represented in the following lists; but all the rest of the area is, I think, very fairly represented. Diorites in a number of instances have been included, while a few rocks of the dyke and effusive acid type have also been included. Fragments of granite occurring as pebbles in the Old Red Sandstones of the North of Scotland as likely to indicate possible variations in the granite masses in a vertical direction in regard to the particular points at issue have also in a number of instances been examined. Purely basic rocks have not been included except in one or two instances, where they have been found to show micropegmatite existing or developed under exceptional conditions.

In the accompanying tables, the granites have been divided into four classes, according to their general basicity or acidity, foliation, etc. Such rocks as diorites, felsites, etc., not strictly classifiable as granites, have been classified with the type of rock to which they are most closely related. To make these tables intelligible at this stage it may be noted that in the columns headed, "Deviations from the Normal Order of Crystallization," the various minerals for the sake of brevity are indicated by their initial letters, and inclusion of one mineral in another has, broadly interpreted, been taken as the general test of the order of crystallization. The various kinds of micropegmatite, limiting the term for the present to the characterisitic quartz-felspar intergrowths, have been indicated by the letters A, B, C, where

A represents micropegmatite on a large scale or the intergrowth of quartz and orthoclase, Pl. XXVII., Fig. 3, quartz and plagioclase, and quartz and microcline, the particular species being indicated in brackets—thus A(Q in O), A(Q in P), A(Q in M). This form has been developed in the regular course of crystallization, but the reasons for this will be considered later. This form is also known as the *Initial* or *Large Scale* micropegmatite.

B represents the centric or radial forms developed in connection with—and radiating from the edges of—the felspars. It is proposed to call this the *Corrosional* form, though the term is perhaps not strictly correct from a theoretical point of view. It has taken origin in consequence of secondary reactions between the various minerals in connection with which it occurs. But the reasons for these views will be discussed later. Apart from these theoretical considerations, it may be known as the *Intermediate* form of micropegmatite.

C represents the form of micropegmatite presented in some cases by the matrix in which the other minerals are embedded. It may be known as the *Final* form of micropegmatite. Microgranite areas occur in some of the granites as well as in some of the other rocks. These are represented in the accompanying tables by the symbol Cm.g.; the ordinary micropegmatite of this type is indicated by the symbol Cm.p.

	Rocks.	No. of Slides examined.	Exceptional Mineral.	Character of Micropegmatite.	Exceptions to Normal Order of Crystallization Observed.
1	Stratherric Granite	5	..	B (Cm.p. ?)	Q, O, P in H; Q, O, P in B; Q in S; Q in O
*2	,, Basic Marginal	1	..	B	Q and O in H; Q in B; Q in O; P in S
3	Ben Laoghal	5	Microcline	None	Q and O in H; Q in P
4	Ben Nevis (Hornblendic)	3	..	B, Cm.g.	Q, P in H; Q, O, P in B; Q in S; Q in O; Q in Mag.; Q in P and P in Q
5	Ballachullish	2	..	B	Q, P in H; Q, O in B; Q, O in S
6	Ben Cruachan	3	..	B	Q, O, P in H; Q, O, P in B; P in S
7	Lairg and Bonar Bridge	6	..	B	Q, O in H; Q, O, P in B; Q in O and P
*8	Auchmair, Cabrach Diorite (Banffshire)	2	Much Orthoclase	B	Q, O, P, H in S; Q, O, P in H; O in P; Q, O in S
*9	Dalltullich Syenite (Nairnshire)	2	Microcline	B	Q, O, P in H; Q in S
*10	Forsinard (Basic), Caithness	1	..	None	Original B in H; O in H
*11	Ben Nevis Dykes	2	..	A, B, Cm.g.	..
*12	Torphins Diorite	1	..	None	P in H
*13	Netherly Diorite, Elginshire	4	..	None	Frequent corrosion of H by B; Q in H
*14	Conrock Diorite, ,,	2	..	None	P in S; Q in H
*15	Dandaleith Diorite, ,,	2	..	None	P in S; Q in H
*16	Blackwater Gabbro, Banffshire	1	Augite	None	..
*17	Hunt Hill Diorite, Elginshire	1	Augite, Hypersthene	None	..
18	Boulder, ,,	1	..	Cm.p.	..
19	Auchmair Syenite, Aberdeenshire	1	..	None	..
*20	Kennethmont Diorite ,,	1	..	None	..
21	,, Granite ,,	1	Allanite	None	P in H
*22	Inveramsay Gabbro, ,,	1	..	B (atypical)	..
*23	Battlehill Hyperite, Huntly	1	Hypersthene, Garnet, Quartz, Orthoclase, Microcline, etc.	B	..
		49			

The 14 rocks marked with an asterisk are not strictly classifiable as granites.

Summary—Rocks examined 23, slides 49. $\frac{A_1, B_{11}, Cm.p._1, Cm.g._2, None_{11}}{23}$

Analysis of abnormalities of crystallization

Q in P in 3 rocks	Q in sphene in 6 rocks	Q in hornblende in 12 rocks
O in P in 2 ,,	O in ,, 3 ,,	O in ,, 8 ,,
Q in O in 4 ,,	P in ,, 5 ,,	P in ,, 8 ,,
		Q in biotite in 7 ,,
		O in ,, 5 ,,
		P in ,, 4 ,,

The Biotite or Mono-mica Granites.

	Rocks.	No. of Slides examined.	Exceptional Minerals.	Character of Micro-pegmatite.	Exceptions to the Normal Order of Crystallization Observed.
1	Ben Nevis acid granite	2	..	A, B, Cm.g.	Q, P in B; Q in P; Q in O
2	Kinsteary, Nairnshire	5	..	B, Cm.p.	Q, O, P in B; Q in P; Q in O
3	Abriachan, Inverness-shire	3	Sphene Fluorspar	A, B	Q, O in B
4	Peterhead, Aberdeenshire	4	Allanite, Fluorspar	A, B	Q in B, P, O; P in B
5	Benrinnes (Red), Banffshire	3	..	A, B	Q in O; O in P
6	Hildesay, Shetland	2	Sphene, Epidote, Allanite	B	Q and P in S
7	Avochie, Aberdeenshire	2	..	B, Cm.g.	Q in O; Q, O in B; Microcline in O and B?
8	Aberchirder, Banffshire	1	..	B, Cm.g.	Q in O
9	Huntly, E. of Battlehill	1	..	B	Q in O; O, P in B
10	Benachie, Aberdeenshire	4	..	B	Q in O, P, B; O in B
*11	,, (peripheral)	3	..	Cm.p.	..
12	Clatt, Kennethmont (peripheral)	2	..	A, B	Q in O, P, B, M
13	Corrennie, Kennethmont	2	Sphene	B, Cm.p. and Cm.g.	..
*14	Tillyfourie Felsite	1	..	Cm.g.	..
15	Dalmunnach, Elginshire	2	Sphene	B, Cm.g.	O in S
16	Knockando, Elginshire	3	..	A, B	Q in O, P, B; P in B
17	Benrinnes (Grey), Banffshire	7	Sphene, Allanite	B [m.p. of Biotite in O]	Q in O, P, B; Q in O
18	Cairngorm	2	..	B	Q in P and O
19	,, Basic?	1	..	A, B	Q in B and O
20	Caithness, Forsinard	2	..	B	Q in O, P, B; O in B
21	Loch Roag, Lewis	4	Sphene, Epidote	A, B	Q in O, P, B
22	Helmsdale, Sutherlandshire	2	..	B	Q in O; P in B
23	Benrinnes (Local)	4	(Biotite Granites)	B	Q in P and O
24	Vein, Netherly Diorite	2	..	None	Q in P
*25	Boddam Porphyry	1	..	Cm.p. very fine	..
26	Cambus of May	1	Sphene	B	Q in O, B and S
27	Vein in Schist Stratherric	1	..	A	..
28	Torphins, Aberdeenshire	1	..	A, B	P in B
29	Glengrant, Elginshire	1	..	None	..
30	Birchfield, Fragment in L.O.R., Rothes	1	..	None	Derived from Glengrant granite
31	Mealmohr, Fragments in L.O.R.	2	(Granites)	B	Derived from Abriachan?
*32	Mealmohr, Fragments in L.O.R.	1	(Felsite)	A	..
*33	Cabrach, L.O.R. Felsites	2	..	Cm.p. and Sphærulitic	..

*34	Sphærulitic Dyke, Skye . . .	1	(Felsite)	A, Cm.p. Sphærulitic	~~Derived from Abriachan~~?
*35	Mintlaw Felsite	1	..	[1] Cm.g. [2] Cm.p.	..
36	Hill of Fare Granite	2	..	A, B	..
37	Rora, Aberdeenshire	1	..	None	..
38	Elchies (Grey), Elginshire . .	1	..	B	..
39	Pegmatite Vein, Aberlour . .	1	..	B	..
40	Corpach, Red Granite . . .	1	..	None	..
41	Elchies Red, Elginshire . . .	1	..	B	..
42	Longmanhill, Banffshire . . .	2	..	A, B, Cm.g.	..
43	Marscow Granophyre, Skye . .	2	Allanite, Augite	A, B, Cm.p.	..
*44	Felsite Fragment, Trias, Elgin .	1	..	A, Cm.p.	..
*45	Quartz Felsite Fragment O.R., Speymouth	1	..	Cm.p.	..
*46	Felsite Boulders Cornacy, Cabrach	2	..	Cm.p. and m.g.	..
*47	Felsite Veins, Ben Cruachan granite	4	..	A, B, Cm.p. and m.g.	..
		96			

Summary—47 rocks ; 96 slides examined $\frac{A_{17}, B_{31}, Cm.p._{11}, Cm.g._{9}, None_{5}}{47}$

The 11 rocks marked with an asterisk are not classifiable as granites.

Summary of anomalies of crystallization :—

Quartz in Orthoclase seen in 18 rocks.
Quartz in Plagioclase seen in 11 rocks.
Quartz in Biotite seen in 14 rocks.
Orthoclase in Biotite seen in 5 rocks.
Plagioclase in Biotite seen in 7 rocks.
Orthoclase in Plagioclase seen in 3 rocks.
Quartz in Sphene seen in 2 rocks.
Plagioclase in Sphene seen in 1 rock.
Orthoclase in Sphene seen in 1 rock.

[1] M.p. = micropegmatite.
[2] M.g. = microgranite.

Double Mica Granites.

	Rocks.	No. of Slides examined.	Exceptional Minerals.	Characters of Micro-pegmatite.	Exceptions to Normal Order of Crystallization Observed.
1	Rubislaw, Aberdeen	3	..	B	Q in O and B ; Q, O in P
2	Kemnay	3	..	B	Musc. before B ; P in B
3	Loch Moy, Inverness-shire . .	3	Sphene at margin of B	B none in marginal	Q in O, P ; Q, P in B
4	Ardclach	2	..	B	Musc. before B sometimes
5	Grantown	1	..	B rare	Q in P and B
6	Aitnoch	2	..	B	Q in O
7	Dorbach	1	..	B rare marginal	Q in O
8	Craigellachie Vein	2	..	B	..
9	Rothes Burn Vein, E. of Diorite	1	..	B	..
10	Rothes Burn Vein, W. of Diorite	1	..	B	..
11	Knockando	1	..	B	..
12	Miltonbrae Fragment in O.R. .	1	..	B	Q in O and P
13	Cabrach Fragment in O.R. . .	1	..	B	Q in O
14	Dyce	1	..	B	Q, P in B ; Musc. occasionally before B
		23		B_{14}	

Summary—14 rocks, 23 slides examined $\frac{B_{14}}{14}$

Summary of anomalies of crystallization—
Q in O=6 ; Q in B=4 ; Q in P=4 ; O in P=1 ; P in B=3 ; Muscovite before B=3.

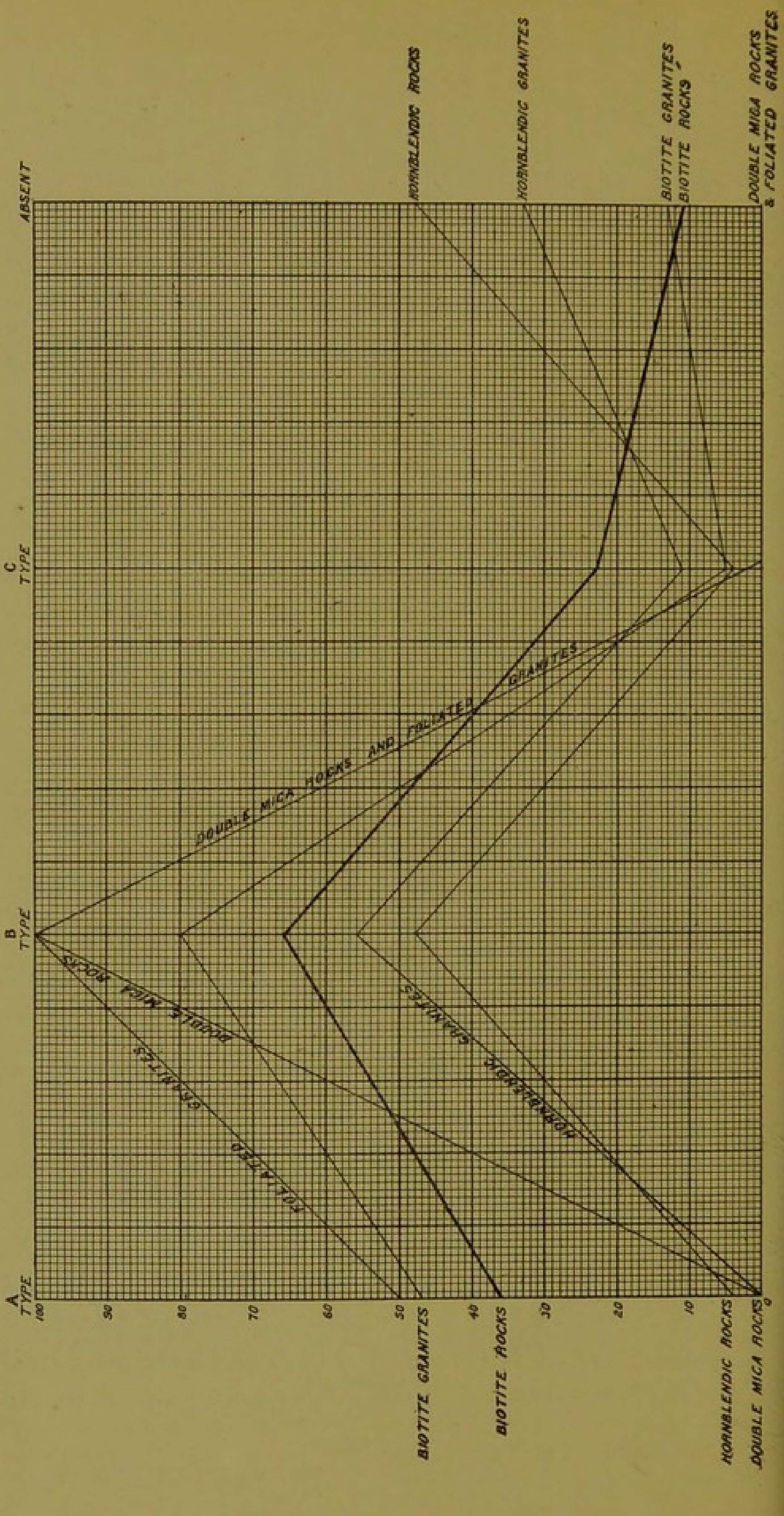
Foliated Granites (Double Mica).

1	Inchbrae	2	..	B	Microcline in O
2	Cabrach	1	..	B	..
3	Portsoy Boggierow	4	(A in O and micro)	A, B	Q in P ; P in B
4	Mulderie	3	..	A, B	..
5	Keith	3	..	A, B	..

Foliated Biotite Granite.

6	Geddes, S.W. Kinsteary, Nairnshire	1		B	Q and P in B ; Micro. intergrown with P
		14			

Summary—6 rocks, 14 slides $\frac{A_3.\ B_6}{14}$



The Distribution of the different kinds of Micropegmatite in the different classes of Granite Rocks.

General summary of rocks examined :—

	Rocks.	Slides.	Micropegmatite.
Basic or Hornblendic . .	23	49	$\frac{A_1, B_{11}, Cm.p._1\ Cm.g._2\ None_{11}}{23}$
Acid (Biotite)	47	96	$\frac{A_{17}, B_{31}, Cm.p._{11}, Cm.g._9, None_5}{47}$
Acid (double mica) . .	14	23	$\frac{B_{14}}{14}$
Acid Foliated	6	14	$\frac{A_3, B_6}{6}$
Totals .	90	182	$\frac{A_{21}, B_{62}, Cm.p._{12}, Cm.g._{11}, None_{16}}{90}$

Generalization as to occurrence of micropegmatite :—

Micropegmatite of the A type seen in	23·3% of rocks examined.	
,, ,, B ,, ,,	68·8% ,, ,,	
,, ,, C ,, ,,	13·3% ,, ,,	
Micrigranitic areas	12·2%	
Absence of any form of micropegmatite	17·7%	

Occurrence of the different forms of micropegmatite in the different kinds of rocks.

	A	B	C		Absent
			m.p	m.g.	
Hornblendic rocks (23) . .	4%	48%	4%	9%	48%
,, granites (9) . .	0%	56%	11%	0%	33%
Biotite rocks (47) . .	36%	66%	23%	19%	10·6%
,, granites (36) . .	47%	80%	5·5%	5·5%	13%
Double mica granites (14) . .	0%	100%	..	..	..
Foliated granites (6) . .	50%	100%	..	..	..

For graphic representation of above see Pl. XXV.

Generalization as to abnormalities in the order of crystallization, stated as percentages of rocks examined :—

Class of Rocks.		Horn-blende.	Biotite.	Sphene.	Plagio-clase.	Ortho-clase.
Horn-blendic rocks	Quartz, seen in . .	52%	30%	26%	13%	17%
	Orthoclase ,, . .	34·7	22%	13%	9%	..
	Plagioclase ,, . .	34·7%	17%	22%	..	..
See Fig. 1, Plate XXVI.						
Biotite rocks	Quartz, seen in . .	..	30%	4%	23%	37·5%
	Orthoclase ,, . .	..	10%	2%	6%	..
	Plagioclase ,, . .	..	14·5%	2%	..	..
See Fig. 2, Plate XXVI.						
Double mica rocks	Quartz	..	28%	..	28%	43%
	Orthoclase . . .	..	0%	..	7%	..
	Plagioclase . . .	..	21%	..	..	..
See Fig. 3, Plate XXVI.						

Over all, the aberrations of quartz from its normal order in the scheme of crystallization are much in excess of those of any of the other minerals, while those of plagioclase are in excess of those of orthoclase. See Fig. 4, Plate XXVI.

General Remarks on the Hornblendic Granites.

Abnormalities of Crystallization.

Of the 23 hornblendic rocks examined, 12 were found to show quartz in the hornblende, 8 orthoclase, and 8 plagioclase. While this result obtains with regard to occurrences in the rocks of this class, there is over all a marked predominance in the tendency of quartz to occur in this connection, while orthoclase and plagioclase, as compared with quartz, are of relatively infrequent occurrence in any individual rock. There would appear to be a tendency for quartz, orthoclase, and plagioclase to occur in association with the hornblende of the hornblendic rocks as regards frequency in an order the inverse of that of their normal order of crystallization. This is not equivalent to the proposition that as inclusions in hornblende these minerals appear in reverse order to that in which they appear in the later stages of the crystallization of a granite. But observation directed to the point really bears out the conclusion that this is the case. Manifestly there must be some reason for this, and this reason will come up for discussion in the theoretical part of the paper. Quartz appears included in the biotite of these granites relatively infrequently when individual occurrences are considered, but relatively frequently as compared with orthoclase and plagioclase when individual rocks are considered. Results show that orthoclase and plagioclase occur somewhat more frequently when taken as individual occurrences, but then the periods of crystallization of these minerals, *i.e.* biotite, orthoclase, and plagioclase, tend to fall more closely together than those of biotite and quartz, in the normal order of crystallization. Quartz, orthoclase, and plagioclase occur as inclusions in sphene, which is tantamount to saying that their crystallizing period has occurred abnormally early in these cases. Here again the individual observations would establish a rate of occurrence in the reverse order of that of their normal order of crystallization, but as these minerals occur as single crystals in single crystals of sphene, no two of them ever occurring in the same crystal of sphene together, it has been impossible, as in the case of hornblende, to establish the conclusion that this is actually the case, though the probabilities are that they really have appeared in the order indicated.

Apart from the definite inclusion of quartz in hornblende, there is a marked tendency for quartz to occur in immediate contact with the hornblende in a number of the rocks. A similar tendency for quartz to occur in immediate contact with biotite

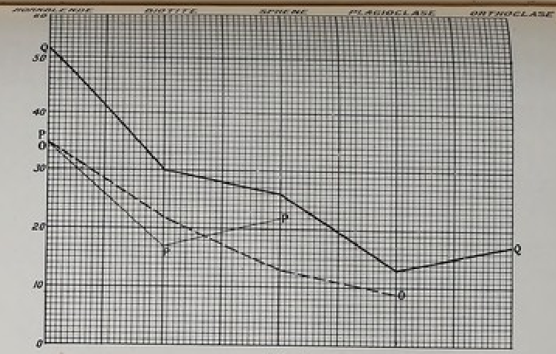


Fig. 1.

Aberrant Crystallisation in Hornblendic Rocks.

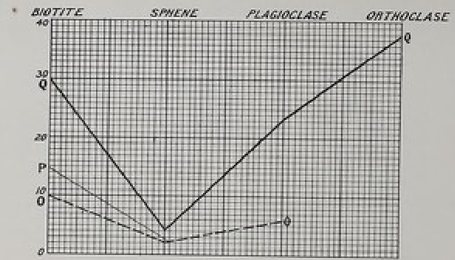


Fig. 2.

Aberrant Crystallisation in Biotite Rocks.

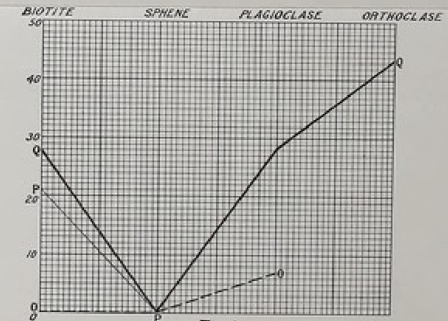


Fig. 3.

Aberrant Crystallisation in Double Mica Rocks.

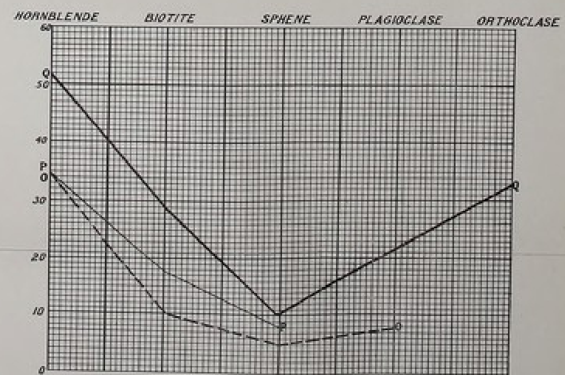


Fig. 4.

Generalised Curve for whole Series.

—even when both occur as inclusions in other minerals such as orthoclase—has also been noted in many of the biotite granites. This relationship has been made the subject of observation in a number of cases under the heading, "Sub-ferromagnesian Quartz," but systematic observations have not been made throughout; but enough has been done to establish the relation as a not infrequent one in many granites.

The Occurrence of the Different Forms of Micropegmatite in these Granites.

In the hornblendic rocks, the occurrence of the A variety of micropegmatite may practically be discounted. The B variety is confined to the granites of the group and is practically absent from the diorites. The Cabrach diorite should really, from the amount of orthoclase in it, be classified as a granite. The C form of micropegmatite is seldom present, but in the section from a large glacial boulder about a mile N.W. of Elgin, it occurs in its typical form. The Ben Nevis granites show a micrograniticmatrix. In the dyke rocks of that mass hornblende is present in very small amount, but it is altogether absent from the sections from the upper part of the granite mass, which have thus been classified with the biotite granites. The Ben Laoghal granite is exceptional among granites generally in showing no form of micropegmatite. The reasons for this will be discussed later. There is very little micropegmatite in the Ben Cruachan and Ballachullish granites, and the latter, as also the Ben Laoghal rocks, are not far removed from diorites. The rocks from near Inveramsay, Aberdeenshire, and from the Battlehill, Huntly, are exceptional, the former being from a white band in the local gabbro, and the latter, though showing no hornblende, being included in this group as a basic rock, because it shows the presence of micropegmatite of the B type developed under abnormal conditions.

General Remarks on the Biotite Rocks.

Abnormalities of Crystallizatiom.

Of the 47 rocks of this class, in which the observations as regards abnormalities of crystallization and the occurrence of micropegmatite have been tabulated, 14 show inclusion of quartz in biotite, 11 in plagioclase, and 18 in orthoclase. As the distance from biotite at which quartz naturally tends to crystallize is greater than that of either plagioclase or orthoclase, one would naturally expect that the order of increasing frequency of inclusion of quartz in these minerals would be—orthoclase, plagioclase, biotite, that is to say, biotite under normal conditions should show the least frequency as regards inclusions of quartz. This abnormal frequency may be taken as indicating a tendency of quartz to occur along with biotite, and thus to bear out the observations made on what has previously been defined as the "sub-ferromagnesian" occurrence of quartz. Orthoclase occurs in biotite in 5 rocks and plagioclase in 7, thus being in some relation to the normal order of appearance of these minerals. Orthoclase occurs in plagioclase in 3 rocks; orthoclase in sphene, which is of relatively infrequent occurrence in purely biotite-bearing rocks, occurs twice, quartz in sphene once, and plagioclase also once.

The Occurrence of the Different Forms of Micropegmatite in the Biotite Rocks.

The A type of micropegmatite has been observed in 17 rocks, the B type in 31, and the C in 11, but the last figure is subject to some modification in consequence of the fact that it is not always possible to distinguish between micropegmatite and micrographic structures when they occur in small amount, and also as they sometimes do in mixed aggregates. There is also some doubt as to whether one or two occurrences should be classified under this type or under the B type. Micropegmatite has not been observed in 5 out of the 47 rocks. It should be noted, however, that a number of these rocks are of a character that precludes observations in regard to the order of crystallization, while a number could hardly be expected to show anything beyond the C type of micropegmatite. Perhaps about 10 of them (those marked with an asterisk) ought to be discounted in this connection.

Generalizations in Double Mica Granites.

Out of 14 muscovite-biotite granites quartz was observed in orthoclase in 6 rocks, in biotite in 4, and in plagioclase in 4. Orthoclase was observed in plagioclase in 1; plagioclase in biotite in 3; and muscovite crystallizing before biotite in 3. These 14 granites, in the slides examined, showed no example of the A type of micropegmatite. All of them show the B variety and none of them the C variety. They are thus characterised exclusively by the B type of micropegmatite.

Generalizations in the Foliated Granites.

The question of the order of crystallization has not been considered in detail in these, as it is complicated in many cases by the results of foliation ; but exceptions have been noted in a number of instances.

Three out of the 6 show the A type of micropegmatite ; all of them show the B type and one or two of them a particular variety of the B type, which it is inferred has owed its origin to the movements that produced foliation. A typical instance of this form was observed in the granite of Boggierow, Portsoy.

In order to facilitate comparison of the different classes of rocks, I have represented in tables the various exceptions to the order of crystallization as percentages of the rocks examined in each class. The same treatment has been extended to the different forms of micropegmatite in another table. The facts may also be represented in graphic form, which probably gives a better idea—and at a glance—of the distribution of exceptions to the normal scheme of crystallization, and of the distribution of the different forms of micropegmatite in the various kinds of rocks.

From either of these modes of presentation it will be evident as regards exceptions to the order of crystallization that the aberrations of quartz from its normal position count for quite half of all exceptions. In the case of the hornblendic rocks, these are seen to occur in greatest numbers in association with hornblende; in the case of the more acid rocks, in association with orthoclase ; that is to say, in highly silicated rocks of both classes, the excess of silica begins to separate in the hornblende rocks with the hornblende—or comparatively early in the scheme of crystallization ; in the non-hornblendic rocks, it separates in greatest abundance with the orthoclase, or comparatively late in the scheme of crystallization, but in both cases in abnormal positions. As regards the intermediate minerals, in biotite for instance, the rate of aberration for quartz is practically equal in all the classes of rocks. In regard to the inclusion of quartz in sphene, it is found to occur in more abundance in the hornblendic rocks ; but that is in great part due to the fact that sphene occurs comparatively rarely in the more acid rocks. Orthoclase and plagioclase occur in the hornblende of hornblende granites with about equal frequency and in about one-third of all the rocks examined. Orthoclase occurs in biotite more frequently than plagioclase in this class of rocks, but plagioclase occurs more frequently than orthoclase in biotites of the other classes of rocks. In the double mica granites, indeed, so far as our observations go, orthoclase does not appear to occur in the micas at all. The fact that the two micas taken together present a general composition which is inclusive of the general composition of orthoclase has probably something to do with this result.

Quartz shows Two Maxima of Abnormal Crystallization.

On the whole, it may be said that as regards its tendency to crystallize at abnormal periods, quartz shows two maxima—one just after the commencement of crystallization in the hornblendic rocks, and another towards the end of crystallization in the more acid rocks. In the latter case, it grades into its normal period of crystallization after the orthoclase.

The Several Classes of Rocks compared as to the Occurrence of Micropegmatite in them.

As regards the occurrence of the different forms of micropegmatite in the different classes of rocks, the A form may be considered as typically absent from the hornblendic rocks. The B form is the commonest form in these, though on the whole it is relatively less frequent in them than in the other classes of rocks. In these the C form occasionally occurs but is infrequent. The A form of micropegmatite is typically present in the most acid class of rocks, being, so far as our observations go, absent from the double mica granites. In the foliated granites again, which probably represent granites originally belonging to both the biotite and double mica groups, the A form is present in 50 per cent. of the rocks examined. The B form appears in increasing abundance in the biotite granites, while it has been observed in every specimen of the double mica granites examined. The C form is relatively infrequent in all the classes, but occurs most often in the most acid rocks, and relatively more frequently in the dyke and effusive rocks of that class than in the typical granites of the same class. The absence of any form of micropegmatite is most marked in the most basic class of rocks, and indeed some inverse relation to basicity appears to be indicated in this negative character in a fairly marked degree, thus bearing out the idea that in the first instance the development of micropegmatite is dependent on composition rather than on any temporary physical condition of the magma, in which it has ultimately appeared. Another feature appears to be indicated in the more basic rocks—the granites show the negative character less frequently than the atypical rocks of that class ; while among the more acid rocks the granites show it more frequently than the atypical rocks of that class. But in the former case, the basis of observation is perhaps somewhat too narrow to found any very broad generalization upon.

One or two points of wide generality emerge in regard to the occurrence of micropegmatite. The presence of the A type is associated with marked acidity of composition. The general absence of any form of micropegmatite is associated with marked basicity of composition. The B form is more characteristic of typical granites than of typical dyke or effusive rocks—indeed, so frequently does this form occur in granites that it may almost be taken as a defining characteristic of a granite. The presence of the C form, on the other hand, is more characteristic of the atypical rocks of the acid class. It will be shown later that the B variety of micropegmatite and the presence of orthoclase or microcline or both go hand in hand, and the two correlatives may be taken as all but defining characters of a granite.

Exceptions to the Normal Order of Crystallization in Detail.

Quartz in Hornblende.

When quartz occurs as an inclusion in hornblende, it frequently occupies a central position in the hornblende aggregates, as if, indeed, it were the very first mineral to crystallize out. It is for the most part of very irregular outline, though occasionally it shows rectilinear outlines. It almost always contains inclusions, which are very frequently small crystals of hornblende itself. At other times, they are magnetite or apatite. I have rarely seen rutile needles in the quartz included in hornblende, though they are of frequent occurrence in the quartz grains of later origin, and in particular in those included in orthoclase. Liquid inclusions with gas bubbles have never been observed in these quartz grains. The occurrence of quartz in hornblende has been attributed to corrosive action set up at a later stage of the crystallization in connection with and as a consequence of the separation of biotite. That such an origin is possible in many instances is not denied ; but the cases tabulated are of instances where no biotite occurs in association with the hornblende groups, and in a number of instances even where biotite is all but absent from the rock. Such, for instance, as in Ben Laoghal granite, Dalltullich syenite, etc. The quartz associated with the worm-eaten appearance of hornblende, which is frequently seen in the presence of biotite, is a totally different manifestation from that now under consideration, and calls for separate discussion. Sometimes a condition simulating a micropegmatite of quartz and hornblende has been observed in some hornblende groups, as for example in Lairg granite, Sutherlandshire, and a rock from Dalltullich, Nairnshire. In the instance observed it has been seen to occupy a central position in the hornblende, being surrounded on all sides by solid hornblende, so that corrosion of the kind just indicated would thus be excluded. It should be noted, at the same time, that a true micropegmatite of quartz and hornblende does occasionally occur. Beautiful examples of this structure have been observed in Lairg granite. The quartz grains occurring in this connection, it hardly needs to be noted, are smaller than the later formed quartz grains of the general rock mass.

Orthoclase in Hornblende.

Orthoclase usually occupies a subcentral position in the hornblende aggregates—that is to say, it is in all probability later in appearing than the quartz. It occasionally presents quite a fresh appearance and is sometimes idiomorphic. In a number of instances it has been found to show Carlsbad twinning, oftener however it occurs in single crystals. Frequently it is hazy and decomposed, and this decomposition is often in striking contrast to the remarkable freshness manifested by the later formed orthoclases. Often it occurs in rounded turbid masses, suggestive of partial resorption before the hornblende finally closed round it. The orthoclases included in hornblende are always smaller than the later-formed orthoclases.

Plagioclase in Hornblende.

Plagioclase, as it appears in hornblende, is usually in small crystals of remarkable freshness, and oftenest occupies a marginal position in the hornblende aggregates. It is not distinguishable from the plagioclases of the general body of the rock except that it occurs in smaller crystals. They look as if their growth had been arrested at an early stage of their development. Pl. XXVII., Fig. 1, from a Banffshire diorite, shows two plagioclases near the periphery of a hornblende crystal, along with quartz and orthoclase in more central positions.

Quartz in Biotite.

This also occurs in very small grains, but they are perfectly clear and show fairly definite outlines. They often have inclusions of apatite, zircon, or magnetite, but no rutile needles or liquid inclusions are observed in them. Hornblende does not occur as an inclusion in the quartz included in biotite, except under conditions where there is reason for believing that the biotite has been derived from hornblende. Quartz resulting from the corrosion of hornblende and augite by biotite is of frequent occurrence, the latter being typically seen in the diorite of Hunthill, Elginshire.

Orthoclase in Biotite.

Orthoclase occurs in biotite much less frequently than quartz, but in the double-mica class of granites it has not been observed in this research in this connection. A reason for this has been already suggested. Where it does occur it usually appears in very small clear grains—not always easily distinguishable from quartz on the one side or plagioclase on the other. Its giving a biaxial reaction in convergent polarised light has been used to distinguish it from quartz, and the absence of lamellar twining to distinguish it from plagioclase. Examples of orthoclase included in biotite are frequent in many granites; typical examples were seen in a section of Cairngorm granite, where two small elongated orthoclases included in a large biotite were observed to extinguish quite differently from the large bounding orthoclases outside the biotite.

Plagioclase in Biotite.

The occurrence of plagioclase in biotite—that is to say, the crystallization of plagioclase before biotite—is not of the same significance as the crystallization of quartz, with or before biotite or hornblende, because in the former case the two minerals crystallize at periods so close together normally that the slight deviation is hardly worth recording. When it does so occur, however, it is always in small crystals, as is usually the case with all these aberrant manifestations. Larger crystals partially embedded in or moulded by the biotite are of frequent occurrence.

Inclusions in Sphene.

The natural crystallization period of sphene should come before that of biotite, if it is not actually contemporaneous with or in some instances even prior to the hornblende period; but there is evidence to show that the crystallizing period of sphene is relatively prolonged, for it has frequently been seen as a fringe of fine crystals on the edges of biotites or occurring in numerous small crystals at a little distance from their margins. The fact that sphene occurs in a proportion of the biotite granites, where there is no hornblende—that is to say, its being of wider distribution in granites than hornblende, is, on the theory of the derivation of biotite granites from originally hornblendic magmas—and of this there is considerable evidence in the area—suggestive that sphene is more soluble at lower temperatures than hornblende, and continues in solution to some extent long after all the hornblende has crystallized out. Where sphene forms relatively large crystals, however, there can be no doubt of its early appearance, and it is just in these large crystals that quartz, orthoclase, and plagioclase occur as inclusions. There can be no question therefore of the early appearance of these minerals under the circumstances indicated.

Quartz in Sphene.

Quartz included in sphene has been seen in quite a number of instances. Sometimes it presents inclusions, as in Pl. XXVII., Fig. 2, from a section of a peculiar rock from Daltullich, Nairnshire, where a fluid inclusion with a bubble is visible along with a minute prism. Fluid inclusions, however, must be exceptional in these circumstances, as this was the only instance observed. The lower part of the quartz grain in this case shows a little fibrous hornblende, a crystal of magnetite, and apparently also a minute sphene enclosed in the quartz. Quartz in sphene has also been seen in Ballachullish granite, the diorite of Auchmair, Banffshire, and elsewhere. The occurrence of the small sphene enclosed in the quartz, enclosed in sphene, in Pl. XXVII., Fig. 2, is analogous to the small hornblendes enclosed in the quartz enclosed in hornblende, of which note has already been made, and probably points to a similar cause.

Orthoclase in Sphene.

Orthoclase in sphene occurs in rounded wavy nodules, occasionally showing Carlsbad twinning, but more frequently not. They give the same suggestion of partial resorption as do some of the orthoclases enclosed in hornblende.

Plagioclase in Sphene.

Plagioclase in sphene occurs in some of the granites, and it has also been seen in several of the diorites. It presents itself in tiny single crystals, showing when in a very fresh state the parallel lamellar twinning. Arrest of growth at an early stage of their development is the impression that they give. It should be noted that all these minerals, quartz, orthoclase, and plagioclase in sphene occur as small single crystals included in single crystals of sphene in every instance.

Quartz in Plagioclase.

The inclusion of quartz in plagioclase is of fairly frequent occurrence and is of relatively more frequent occurrence in the acid granites. The forms in which it appears hardly call for remark, but the individual grains are usually small and of irregular outline. Another feature is that they seldom show any inclusions. It should also be noted that the tabulated results do not embrace cases of large scale micropegmatite of the quartz-plagioclase variety. These are classified separately in table below.

Orthoclase in Plagioclase.

The inclusion of orthoclase in plagioclase has been noted in a few cases, but, in some of these, the occurrence does not indicate that the crystallization of orthoclase took place previous to that of plagioclase. In some cases it is very evident that the orthoclase has followed the plagioclase. Instances have been observed in Benrinnes granite, where the orthoclase is seen to fill up the spaces in a previously corroded plagioclase. It has also been observed in a similar relation in a rock which has been subjected to metamorphic action from the Battlehill, Huntly. Cases of the simultaneous development of orthoclase and plagioclase, however, do occur, and a typical instance was observed in a section from Benachie granite; but such cases as this last manifestly fall under the category of "Minerals other than Quartz and Orthoclase, showing micropegmatite intergrowth," and such occurrences will be more fully discussed along with these.

Quartz in Orthoclase.

Inclusions of quartz in orthoclase are of frequent occurrence. Here occurs the second maximum of aberrant quartz crystallization, but in this case it appears in close proximity to its normal period of crystallization. It appears to be a general law with regard to these aberrant forms that a particular mineral shows a tendency to increased frequency of occurrence in an abnormal position, as its natural period of crystallization is approached. This is what might naturally be expected. The quartz grains occurring in orthoclase often show roughly idiomorphic outlines—in the case of large scale micropegmatite very frequently so, but that particular case is reserved for separate consideration and has not been included among the tabulated exceptions. In another and relatively large number of cases the quartz occurs in orthoclase in rounded grains, which give the impression of partial resorption before their inclusion in the orthoclase. Examples of this are seen in a highly acid granite associated with the diorite of Aberdeenshire, notably also in Loch Roag granite, Lewis. In Ruthrie granite, Aberlour, and Rubislaw granite, Aberdeen, it is also typically seen in this rounded form in the orthoclase. In Benrinnes granite again, the quartz and orthoclase have crystallized so nearly together that numerous instances of the more definite large scale micropegmatite of the (Q-O) type occur along with large patches of an indefinite mixture of quartz and orthoclase so arranged that the quartz appears to fill the spaces of a spongework of orthoclase (Spongiform-orthoclase). The quartz in these instances extinguishes irregularly in patches and occurs in irregular grains, though they usually show some degree of rounding, while the orthoclase extinguishes more or less simultaneously throughout.

The inclusions seen in the quartz included in orthoclase frequently differ from those seen in the later formed quartz grains. They also differ again from those seen in the early occurring quartz associated with hornblende and biotite. Rutile needles frequently occur in those included in orthoclase, while they may be absent from those of later formation. In a section from a granite vein near Craigellachie Bridge, I observed that all the smaller quartz grains—those included in the orthoclase, etc., showed numerous rutile needles while the larger and later formed grains were entirely free from them. While inclusion of one mineral in another has been made the test of the order of the crystallization of the different minerals in a granite, it will be evident that a considerable proportion of a given mineral, say quartz may have crystallized out at an early period ; part of it may have been included in a later forming mineral, say orthoclase, while the other part, though crystallizing equally early, has not been so included in orthoclase or any other mineral, but, remaining free, has at a later stage formed nuclei for later-forming quartz to grow round. In this way we may account for local differences in the inclusions seen in the quartz of some of the granites, each part of a quartz grain as it were taking up the inclusions of its own particular period of development. In this way we should also be able to account for the presence of a particular class of inclusion in one set of quartz grains and their absence from another set in the same granite. Two cases may be cited in illustration. In Benrinnes granite rutile needles frequently occupy a central position in some of the quartz grains, while they are absent from the periphery of the grain. From other grains they are entirely absent. In a granite vein in close association with the Netherly diorite—if it does not actually invade it—large rutile needles are present in the quartz, but they always occupy an excentric position in the grains, the rest of the grain being entirely free from them. In Rubislaw granite, again, rutile needles occur locally and often show a radial arrangement in some grains while they are altogether absent from others. They frequently appear in the quartz included in the orthoclase, however, where they show a similar radial arrangement. Hence we infer that there may have been two series of quartz nuclei, one of earlier development and another of later. Of the former series, one set may have been included in orthoclase and the other in quartz. These would both exhibit rutile needles, the latter included in the quartz however only centrically and locally. The later series of quartz nuclei developing at a different period would be absolutely free from rutile needles, both centrically and peripherally. This view, I venture to think, will explain many anomalies shown by quartz grains, and probably by other minerals also, in regard to variations of their inclusions even within the compass of the same rock-slice. In support of this view we have, as we shall see, the analogous case of orthoclase (as seen in a fine grained granite from Dalmunach, Elginshire), where we have evidence that later formed orthoclase has formed round corroded nuclei of orthoclase of an earlier development. It may be well to state that though "rutile needles" have been taken as the type of the foregoing illustrations, the scheme suggested is by no means confined to quartz grains enclosing these needles, but may be freely extended to other quartz grains showing other inclusions which are known to have a definite period of appearance, such for instance as the small idiomorphic hornblendes exhibited by the quartz included in hornblende, etc.

General Conclusions as to Deviations from the Normal Order of Crystallization.

The following conclusions are deduced from an examination of the deviations from the normal order of crystallization :—

(1) Quartz is by far the most aberrant mineral as regards its period of crystallization, its occurrence in abnormal positions being equal to those of orthoclase and plagioclase together.

(2) Taking all the classes of rocks together, quartz shows two maxima of aberrant crystallization, one in the hornblende of hornblendic rocks, the other in the orthoclase of the more acid rocks.

(3) The maximum of aberrant quartz in the hornblende is correlated with a minimum in the orthoclase of the hornblendic granites.

(4) Orthoclase shows a maximum of abnormality in the hornblende, and steadily declines to a minimum in the plagioclase, but this minimum is subject to a further deduction for cases where orthoclase has developed in the plagioclase at a later stage, as the result or at least the consequent of the corrosion of the plagioclase.

(5) In the hornblende and biotite of hornblendic granites, quartz, orthoclase, and plagioclase show a frequency of occurrence in the reverse order of their appearance in the later stages of

crystallization of a granite, and observation of their relative positions in the hornblende aggregates supports the view that they have actually appeared in the hornblende in an order which is the reverse of that of their normal order of crystallization.

(6) In the acid rocks, orthoclase is the least aberrant of the three minerals.

(7) In sphene these minerals appear to follow a similar order to that observed in the hornblende and biotite, but the number of observations in this case have been too few to warrant a very authoritative conclusion on the point.

(8) Resorption previous to their inclusion in the various minerals is suggested by the form and appearance of the orthoclases included in hornblende and sphene, and the form of some of the quartz grains included in the plagioclases and orthoclases.

(9) The inclusions in the different classes of aberrant quartz grains vary according to their period of development, and according to the minerals in which they are included. In the quartz in hornblende they are chiefly hornblendes; in the quartz in biotites they are chiefly apatites, sphenes, and magnetites; from the quartz in plagioclase they are absent, while in that in orthoclase, they are chiefly rutile needles. From the quartz of the A type of micropegmatite, again, inclusions are almost invariably absent.

(10) A study of the inclusions in the quartz of granite generally, from the observed variations in character and distribution of these inclusions in the several grains, suggests the origin of quartz nuclei at different stages of the crystallization and their renewed growth at subsequent stages, each zone or division of a quartz grain being characterised by inclusions of its own particular period of origin.

The A Type of Micropegmatite.

The A type of micropegmatite, as already stated, is practically confined to the most acid class of granites, and there can be no question that acidity or silica-saturation is a condition of its development. A granite magma that contains excess of silica is naturally one that will deposit such excess on the first opportunity. This will naturally be in abnormal positions in the scheme of crystallization, and of necessity in advance of its normal period on the first failure of the conditions that make for its solution. There is unequivocal evidence in a number of instances that this form of micropegmatite has appeared relatively early in the scheme of crystallization, and this raises a presumption that it has done so in other cases, where there is no direct evidence on the point. In a section from a fragment of a felsite from the L.O.R. of the Mealmohr, it is seen both in the orthoclase and plagioclase, as porphyritic aggregates, in a microfelsitic base. With the exception of very small quartz grains and felspars, these micropegmatite aggregates are the only definite crystalline elements present. But there may be an earlier form than that now indicated. The inclusion of the quartz in the felspar strictly interpreted means that the quartz must really have appeared first; and a stage could be conceived in which the quartz would be present without the including felspar. Such a case was seen in a section from another felsite fragment from the Elgin Trias. The specimen is a poor one, but shows unmistakably the quartz in an arrangement typical of micropegmatite, but except over a very limited area, without the ordinary supporting felspar. In the granites also one or two instances have been observed which show that this form has developed early. Thus in an example from Peterhead granite the micropegmatite group was seen to be all but surrounded by biotites. This would indicate that the particular structure must have been developed before the biotites finally closed round it. Again it has from time to time been observed that orthoclase showing this, the A type of micropegmatite, at the same time shows a fringe of the B type towards another orthoclase. This, as we shall see later, is evidence that the orthoclase containing the A micropegmatite, is of earlier development than the adjacent orthoclase. Similar relations between a plagioclase showing the A type of micropegmatite in relation to microcline are seen in Pl. XXVII., Fig. 4. While these observations point naturally to a relatively early development of the A form of micropegmatite, the instances of its occurrence from internal evidence support the view that they have all of them been developed on the orthoclase-quartz borderland so to speak, in other words they have appeared during a period partially overlapped on opposite sides by the orthoclase and quartz crystallization periods. At the centre of most of these areas of micropegmatite, the orthoclase will be observed to occupy the larger superficial area of the section. Traced outwards, however, from the centre toward the periphery, the areas occupied by the quartz gradually increase, the felspar at the same time getting less and less, till finally quartz alone occupies the periphery, and thence merges into the general quartz of the rock mass. This was seen in particular in the specimens from Ben Nevis granite, both in regard to plagioclase and orthoclase, Photograph 3, Pl. XXVII., is from this granite. The theoretical considerations suggested by these appearances will be discussed later. Another manifestation of less frequent occurrence, and of less symmetrical appearance, is seen in both orthoclase and plagioclase, where a number of irregular quartz grains are set irregularly in a base of felspar, whether of orthoclase or plagioclase. The quartz grains extinguish simultaneously perhaps with one or two exceptions, but there is little or no symmetry either in their form or their arrangement in the felspar matrix.

In the granites, in which the A type of micropegmatite occurs in abundance, it may be taken as indicating a transition towards the structure of the granophyres. Occurring as it does in the most acid granites, it also indicates that these approximate most closely to the granophyres. Another indication will be touched on, when we come to discuss the theoretical side of the question. The A form of micropegmatite is of remarkably frequent occurrence in Ben Nevis and Benrinnes granites. The approximation of these granites to the granophyres in a special degree as compared with the other granites is thus indicated.

The Forms of A Type of Micropegmatite and where observed.

Rocks.	Forms of Micropegmatite.
1. Ben Nevis granite (biotite)	Q in O and Q in P
2. Abriachan . . .	Q in O
3. Peterhead . . .	Q in O
4. Benrinnes . . .	Q in O
5. Knockando . . .	Q in O
6. Aberlour . . .	Q in O [not typical]
7. Cairngorm . . .	Q in O
8. Loch Roag . . .	Q in O, Q in microcline
9. Vein Schists Stratherric .	Q in O
10. Ben Nevis (hornblende) .	Q in P
11. Benachie . . .	O in P
12. Longmanhill . . .	Q in P
13. Hill of Fare . . .	Q in P
14. Torphins . . .	Q in O, Q in microcline
15. Marscow, Skye . .	Q in O
16. Sphærulite Dyke, Broadford	Q in O
17. Mealmohr Felsite Pebble, L.O.R.	Q in O, Q in P
18. Foliated granite, Portsoy	Q in O, Q in microcline
19. Foliated granite, Mildere, Keith	Q in O
20. Foliated granite, Keith Town	Q in O
21. Foliated granite, Geddes, Nairn	Microcline in P
22. Diorite, Kennethmont .	P in O

Rocks.	Forms of Micropegmatite.
23. Ballachullish granite .	P in O
24. Diorite Dandaleith, Morayshire	H in P. Case of plagioclase ophitically surrounding hornblendes.

Analysis of occurrences—

Q in O	=62% of total occurrences		
Q in P	=21%	Microcline in P	=4
Q in microcline	=12·5%	P in O	=8
O in P	= 8%		

Relative Frequency of Occurrence of the different Forms of the A Type of Micropegmatite.

As regards the relative frequency of the different pairs of minerals, observed as occurring in this type of micropegmatite, the quartz and orthoclase type is by far the most frequent and amounted to 62 per cent. of the occurrences tabulated. At the same time, it occurs in the most typical forms. Quartz in plagioclase comes next, showing 21 per cent. of the total occurrences; while quartz occurring in microcline in micropegmatite arrangement has been seen in three granites or 12·5 per cent. These are Torphins, Loch Roag, and Portsoy foliated. In these it has been seen in typical manifestations.

This form of micropegmatite, it is evident, has developed, except in the exceptional cases cited, in the direct line of crystallization. In this respect, as we shall see, it differs from micropegmatite of the B type, in which we have reason to believe the manifestations are exclusively the result of recessional processes, that is to say, they have taken origin in connection with changes taking place in a reverse direction to the general order of crystallization.

Minerals other than Quartz and Felspar occurring in Micrographic Intergrowth.

While the A type of micropegmatite, in which quartz and one or other of the felspars are the participating minerals, occurs with a frequency which is out of all proportion to that of the other forms, it must not be concluded that this particular form of arrangement is confined to those just described. Other pairs of minerals showing a similar arrangement have from time to time been met with and are of sufficient frequency of occurrence to show that under special conditions they might be expected to occur with even greater frequency. Indeed, so many instances of different pairs of minerals have been observed in micrographic or micropegmatitic intergrowth, that the following generalization does not appear to be much, if any, in excess of the facts :—*Any two minerals, whose periods of crystallization overlap, even where one of them is crystallizing at an abnormal period, may appear in micrographic intergrowth ;* and as regards frequency of occurrence *the relative frequency of occurrence of any single pair in such combination is in proportional relation to the general coincidence of the crystallization periods of the particular minerals entering into the combination.* To illustrate, we have seen that quartz and hornblende may crystallize at the same time, the quartz in this case crystallizing at an abnormal period, and by implication the crystallization of quartz at this period is a relatively infrequent occurrence. Again the normal crystallizing periods of quartz and orthoclase fall close together. Hence they tend to overlap relatively frequently. Quartz and hornblende occur in micrographic intergrowth, and so of course do quartz and orthoclase. But the occurrence of the former pair in this particular arrangement is relatively infrequent, while the occurrence of the latter pair is relatively very frequent.

I shall now set out in tabular form the occurrences of combinations other than those of the ordinary quartz and felspar type, that have been observed in this research. Of the 7 commonly occurring minerals in granite 21 combinations are possible, taking them two at a time. We may, however, consider two phases in each case ; for example, quartz in hornblende might be considered the positive phase, while hornblende in quartz would be the negative phase of the same combination. There would thus be 42 possible combinations of the 7 commonly occurring minerals taken two at a time.

Minerals other than Quartz and Felspar occurring in Micropegmatitic Intergrowth.

Combinations.	Whether observed and where.
Quartz-Hornblende	Lairg granite
Orthoclase-Hornblende Plagioclase-Hornblende	Single crystals of orthoclase and plagioclase in hornblende in nearly all hornblendic granite but no typical micropegmatite of the latter two with hornblende
Hornblende-Plagioclase (negative phase)	Dandaleith diorite
Sphene-Hornblende	Ben Cruachan
Magnetite-Hornblende	Ben Cruachan, Ballachullish
Microcline-Hornblende	Not observed

Combinations.	Whether observed and where.
Biotite-Hornblende	Basic margin of Forsinard granite
Quartz-Biotite	Hildesay granite, Netherly diorite
Orthoclase-Biotite	Marginal Benrinnes at W. Elchies
Biotite-Orthoclase (negative phase)	Aberlour granite
Plagioclase-Biotite	Single crystals of former in latter frequent
Quartz-Orthoclase	Benrinnes, Ben Nevis Peterhead, Abriachan, Loch Roag, etc. See table
Orthoclase-Quartz (negative phase)	Ben Nevis
Quartz-Plagioclase	Ben Nevis, Longmanhill, Hill of Fare, etc.
Orthoclase-Plagioclase	Benachie, Benrinnes, etc.
Plagioclase-Orthoclase (negative phase)	Kennethmont diorite, Battlehill hyperite, Ballachullish granite
Quartz-Microcline	Loch Roag, Torphins, Portsoy
Orthoclase-Microcline	Not observed
Plagioclase-Microcline	Not observed
Microcline-Plagioclase	Geddes (foliated)
Quartz-Sphene, Plagioclase-Sphene, Orthoclase-Sphene	Confined to single crystals of these minerals enclosed in sphene. From size of sphenes more could hardly be expected.
Biotite-Sphene	Ben Cruachan fairly typical margins of biotite, Cabrach diorite and Moy (peripheral).

The following have been observed in the case of epidote in Hildesay granite :—

Quartz-Epidote.
Epidote-Orthoclase.

If we discount doubtful cases, such as the sphene and hornblende single inclusions of quartz, orthoclase, and plagioclase, 15 different combinations out of a possible 42 have been observed. This is an unexpectedly high proportion. It has been observed, however, that some of the alternative phases do not bear out the view of simultaneous crystallization even in a broad sense, but are evidently of secondary development. Of these may be noted, the plagioclase-orthoclase and the microcline-plagioclase combinations. In the former case, corrosion of the plagioclase previous to its inclusion in the orthoclase as in Kennethmont diorite, Ballachullish granite, etc., is indicated ; while in the latter case, the plagioclase has also been corroded before the microcline developed in the interspaces produced by corrosion. The same is true of several of the instances where orthoclase has developed in the spaces of corroded plagioclase, *e.g.* in Benrinnes granite, Battlehill hyperite. In some instances, however, *e.g.* in Benachie granite, simultaneous crystallization is indicated in the plagioclase-orthoclase combination. On the whole, in view of the combinations that have actually been observed, it may be said that some of the minerals crystallize at periods so far apart that their occurrence in micropegmatitic intergrowth must be of the greatest rarity. This must be the case with hornblende and microcline, which seem to be relatively incompatible minerals. They have been observed together in only two or at most three of the rocks examined—in the Ben Laoghal granite and the Dalltullich syenite from the Nairn valley. One crystal of a very fine microcline has been seen in Stratherric granite out of some 7 slides examined. As we shall see later, this latter crystal has yielded important results in connection with the B type of micropegmatite. The relatively long distance between the crystallizing periods of hornblende and microcline even where they occur together, and apart altogether from the relative infrequency of their simultaneous occurrence, must be a decided bar to their appearing in micrographic intergrowth.

The question of an early crystallization of microcline similar to that obtaining in the case of quartz, orthoclase, and plagioclase in association with hornblende is one that has been raised, but such observations as have been made are equivocal and still leave the question an open one. On theoretical grounds, however, if quartz, orthoclase, and plagioclase occur in this association, and of that there cannot be any doubt, there is no good reason for concluding that microcline may not also occur in the same association. This is a point that might very well be reserved for future observation.

The B Type of Micropegmatite.

This type of micropegmatite is much more widely distributed than either the A or the C type—indeed, typical granites almost always show it in greater or less amount. The exceptions are so very few that we must conclude that it owes its origin to conditions that have occurred much more frequently during the development of rocks of granitic character than the conditions that have given rise to either the A or the C type, and that these conditions were at some period of their history all but co-extensive with the rocks themselves. In the case of the A type we found that one condition of its development was dependent on composition, and we shall also find that this is probably also true of the C type. The B type is more variable in its manifestations, and its origin and process of development are much more recondite than those of either of the other two. Though it occurs less frequently in the hornblendic than in the acid granites, I hope to show that this is not in the first instance a question of composition so much as a question of the presence in quantity of a particular mineral; but the further consideration of the point must for the present be left to the theoretical part of the paper. I shall now give a general description of the different forms which manifestations of this type present, classifying them as far as may be possible and at the same time pointing out their relations to the minerals with which they are associated.

(1) The B type of micropegmatite in a relatively large number of instances takes the form of rounded and more or less corroded-looking masses of plagioclase, wholly or partially embedded in orthoclase or microcline (Pl. XXVII., Fig. 4, and XXVIII., Fig. 5). These plagioclases are seen in all stages of attenuation, from such as show only a few radiating streaks of quartz in a rounded edge of the plagioclase crystal up to all but total extinction; indeed, only a few pegs of quartz may be all that remain to indicate their original existence, as typically seen in some of the sections from the Caithness granite, or they may exist as wispy or hazy nebulous masses, sometimes rendered evident only in polarised light as indefinite nebulæ in the midst of the orthoclase. All stages are traceable, and it is reasonable to suppose that some of them "have like the unstable fabric of a vision faded and left not a wrack behind." In the plagioclases which have undergone less change the lamellar twinning is plainly visible, even where the individual unit is wholly enveloped in orthoclase, and shows very fine micrographic quartz throughout its whole extent. Others show the quartz in grosser forms and the twinning in broader bars (see Pl. XXVIII., Fig. 5).

A relation has been noted between the distance a plagioclase extends into an orthoclase or microcline crystal and the development of the micropegmatite structure in it. In the case of plagioclases partially embedded in orthoclase, it has time and again been observed that the structure is confined to the embedded part. This is, I think, more frequently displayed when their ends project into the orthoclase, though cases occur where the sides are similarly attacked. Of the former, typical examples have been seen in sections from Ruthrie, Stratherric, Lairg, and other granites. In the last particularly, two plagioclases have been seen projecting into a single orthoclase, one from either end. In one instance, a small central quartz was observed in the orthoclase. In another instance in a section from Loch Roag granite four plagioclases were seen projecting into one orthoclase; one of these presented its side to the orthoclase, the other three had their ends projecting into it. When the plagioclases are totally surrounded by the orthoclase or microcline the degree of change they exhibit bears some relation to their distance from the margin of the including mineral, and this may be said to be roughly in the inverse ratio of their distance from the margin of the crystal. Beyond a certain distance they exhibit only the ordinary clear margins and dark centres usually seen in zoned albites, but I am strongly of opinion that these clear outer zones, in some instances at least, exhibit what may be considered the very first stage of the process that eventually ended in the development of micropegmatite. In a number of instances, on carefully tracing round these clear bounding zones under a high power, I have found them to show locally at least the unmistakeable characters of micropegmatite. This clear margin of the albites has been commonly attributed to a change of composition in the direction of greater acidity in the outer zone. In view of these observations, my own opinion is that this manifestation in some instances is to be attributed to the same conditions as led up to the development of micropegmatite. In only a small proportion of the granites have plagioclases exhibiting micropegmatite been observed completely surrounded by orthoclase and microcline. Among these are—Stratherric, Benrinnes, Corrennie, Caithness, etc.

(2) In a large number of cases the micropegmatite is found to occur where two felspars meet and takes the form of radiating arborescent fringes spreading from the one mineral towards or into the other. It is exceptional to find them radiating from both minerals, though this has also been occasionally observed, and will be described under another class. Where it has been possible to determine the relative ages of the two felspars in contact, I think that without exception the micropegmatite structure has been found to radiate from the older into the younger crystal, that is, from the earlier into the later mineral to crystallize, whether the felspars are plagioclase, orthoclase, or microcline. Hence, when it appears between plagioclase and orthoclase, it radiates from the plagioclase towards or into the orthoclase; when between two orthoclases and their relative ages can be determined, it is from the older towards the younger. A case in point was seen in a granite from near Huntly, Aberdeenshire, where an orthoclase without micropegmatite was seen to mould

another from which the micropegmatite radiated. If orthoclase and microcline come together, it radiates from the orthoclase towards or into the microcline. When plagioclase and microcline come together, it also radiates towards the microcline. Where it has been seen in connection with microcline, no matter what the other felspar, it has always been observed to radiate towards or into the microcline. It has never been observed between two plagioclases. It has very rarely been seen between quartz and any of the felspars. Frequently, indeed, on tracing the boundaries of a felspar, the margins of which show micropegmatite structure, it has been found to stop abruptly opposite a quartz crystal. This form may be known by the name of "fringing" micropegmatite.

(3) In a relatively small number of instances "fringing" micropegmatite is developed in each of the two felspars along their line of contact, and in some of these the areas of micropegmatite are found to extinguish in a remarkable manner. The patches on one side of the line of contact are seen to extinguish with the felspar on the opposite side of the boundary line. A typical example of this is figured in Pl. XXVIII., Fig. 6, from Kinsteary granite. To this variety the name of "alternate fringing" micropegmatite has been given. The double line of micropegmatite between two felspars without this alternation of polarisation effects might be called "simultaneous fringing micropegmatite."

(4) Again, in a number of instances, it is possible to follow lines of micropegmatite, which may be single or double according to the bounding minerals, in radiating, irregular but continuous lines around and between the margins of the crystals for considerable distances. These suggest the presence at a certain period of the development of a liquid circulating around and between the minerals along these lines in these particular instances. Examples have been observed in Kinsteary, in Hildesay (see Pl. XXVIII., Fig. 7), and Lairg granites. This form may be known as the "extended fringing" micropegmatite.

(5) At other times areas of micropegmatite extinguishing in patches as the nicols are rotated, are seen at points where several felspars or other minerals meet and give the impression of original lacunæ which have been filled up at a later date by the crystallization of the contents as micropegmatite (Stratherric and Kinsteary granites). In other instances the original lacuna is filled by a central orthoclase, the felspars along the margins showing micropegmatite wherever they border on the lacuna (Pl. XXVIII., Fig. 8), or the central felspar is accompanied by discrete marginal plagioclases showing abundant micropegmatite. These may be known as varieties of the "lacunar" type of

micropegmatite. It is doubtful whether some instances of this type should not be classified as examples of the C type.

(6) Expansional and at the same time what look like corrosional forms of micropegmatite are occasionally seen in one of a pair of albite twins. The twin which shows the micropegmatite may be expanded to twice the breadth of the other twin at the part showing the micropegmatite and be attenuated or practically undeveloped at the other. Examples from Ruthrie granite in particular have been observed. Another form is the single isolated "skeleton" plagioclase of which examples from the same granites have been noted. Another fine example was observed in a basic specimen from the margin of Stratherric granite.

(7) A feature which has been noted again and again is the aggregation of plagioclases showing micropegmatite in their structure along the margins of the orthoclases and microclines in some granites, and typically seen in Stratherric granite, though the feature is by no means confined to it. The appearance suggests that the orthoclases or microclines in crystallizing had pushed aside the plagioclases, which up to that time had been floating freely in the magma, in this way collecting them and concentrating them between the advancing orthoclase or microcline and the minerals which had already crystallized out. In a specimen of Peterhead granite a protruding plagioclase appeared as if it had been pinched off by the growing orthoclase and carried before it towards the margin of the orthoclase, the straggling mass of the pinched off micropegmatitic plagioclase extinguishing simultaneously with the plagioclase, from which it had been presumably carried away. Frequently fringes of micropegmatite around orthoclases and microclines are seen to extinguish in clumps suggestive of their having been originally minute plagioclases or orthoclases, though all traces of plagioclase structure may be obliterated. Occasionally, however, they do unmistakably show that structure. The fact that such clumpy micropegmatites, even when they are backed up on the side remote from the orthoclase or microcline by micrographic areas, invariably turn their convex or micropegmatised sides towards the orthoclase or microcline and away from the micrographic areas, suggests, on the induction as to relative age in such cases which has already been made, that these clumpy micropegmatite areas were originally really minute plagioclases.

(8) Manifestations referable to the "lacunar" form of micropegmatite are seen in some granites where part of an orthoclase crystal is replaced by micropegmatite without any indication of the original presence of plagioclases in the area. Examples have been seen in Stratherric granite, and should probably be preferably classified with the C type of micropegmatite.

Relations of the B Type of Micropegmatite to Minerals other than the Felspars.

Frequently on tracing round the contours of an orthoclase or microcline, an area of micropegmatite is observed in immediate relation with a biotite, less frequently in relation with a hornblende, crystal. Only once has it been observed in association with sphene. These areas always present their convex side to the orthoclase or microcline, but the biotite, hornblende or sphene from which they radiate, is not observed to have undergone any change. Occasionally in the case of biotite the mineral has been found to be stained with ferric hydrate in immediate relation to the micropegmatite area, but it is exceptional for any other indication of chemical change in that mineral to be observed. Where plagioclases occur in immediate relation to orthoclase or microcline on the one side and biotite or hornblende on the other, they are found to show micropegmatite of a specially intense form. An instance of the development of micropegmatite in relation to biotite is seen in Pl. XXVIII., Fig. 8, where the large mass radiating into the orthoclase to the left radiates from a small biotite. The probable significance of these occurrences will be discussed in a later part of this paper. A particular instance of the occurrence of micropegmatite in relation to epidote was observed in Hildesay granite. There the micropegmatite was seen to radiate into the orthoclase on the one side of the line of junction and into the epidote on the other. In this respect epidote shows a marked difference from biotite and hornblende in similar circumstances. The difference in the character of the micropegmatite in the orthoclase and in the epidote was also a feature calling for special remark.

The Periods of Appearance of the B Type of Micropegmatite.

In two or at most three granites only have felspars showing this type of micropegmatite been observed entirely surrounded by or included in the biotite aggregates. These felspars are difficult to refer with certainty to their respective species, as they exhibit a degree of haziness and turbidity that is inimicable to exact determination. That they are orthoclases in some cases cannot, however, be doubted. The granite in which most of the examples of this type have been observed is the Ruthrie or Aberlour grey granite. They have also been observed in Stratherric granite in a single instance, and in Loch Roag granite also in a single instance. That they belong to a period earlier than, or at least synchronous with, the development of the biotites seems probable. Their relative infrequency of occurrence raises a point as regards their origin, and suggests the possibility of their being xenocrysts, derived from pre-existing rocks. This is possible in the case of the Ruthrie rock, which is of subsequent date to the ordinary red Benrinnes granite of the area. But as the occurrence of orthoclase and plagioclase included in biotite is relatively infrequent under any circumstances, their micropegmatisation under such circumstances must be more infrequent still. I think, however, it will be found possible to explain these occurrences in a manner which will be quite compatible with our general view as to the origin of manifestations of the B type of micropegmatite generally.

As a large number of the manifestations of the B type are referable to plagioclase, the period of appearance of the micropegmatite must be posterior in time to the crystallization of that mineral, and as a proportion of these are included in orthoclase the change in the plagioclases must have taken place before the completion of the crystallization of the orthoclase. The examples occurring as fringes to orthoclase and radiating into surrounding orthoclases have necessarily appeared before or simultaneous with the completion of the crystallization of the latter orthoclase. The same conclusion holds in the case of the lacunar forms with a central orthoclase. A proportion of the manifestations must therefore be referred to a late date in the period of crystallization of the orthoclase. Again as, in a proportion of cases, these manifestations exhibit the same relations to microcline as the others do to orthoclase, these must be referred to a similar position in the crystallizing period of the microcline. None of the manifestations of the typical B variety, with the exception of the few included in biotite already mentioned, appear except in relation to orthoclase and microcline, so that the periods of appearance are definitely tied down to two or at most three periods. These are :—

(1) A few early and exceptional examples which are possibly but not necessarily referable to a period anterior to or synchronous with the appearance of biotite.

(2) A large proportion of the manifestations referable to a date relatively late in the period of crystallization of the orthoclases.

(3) Another and fairly large proportion referable to a corresponding date in the period of crystallization of the microcline.

Some examples such as those of the " lacunar " and " extended fringing " types cannot from internal evidence be tied down to any particular time, but a late period in the crystallization of the granite is evidently indicated—indeed, it is possible that some of these are really referable to the period of development of the C type of micropegmatite as already suggested.

Actual Observations bearing on a Double Period of Development of the B Type of Micropegmatite.

The actual observation of appearances pointing to the development of micropegmatite of the B type at two different periods, has been made in one or two instances. It would be natural to infer, in view of what has just been said, that one of these would be found synchronous with the development of orthoclase and the other synchronous with the development of microcline. Nothing to indicate such a relation, however, has been noted in the one or two instances, where the appearances occur, and it does not necessarily follow that their periods of appearance have been as indicated. One occurrence of two areas of micropegmatite of very different degrees of fineness in close association was observed in a double-mica granite from Aitnock Hill, Dara, Morayshire, where an area of coarse micropegmatite, probably representing an original plagioclase, was seen to be separated from biotite by an area of very fine micropegmatite. Both orthoclase and microcline, the latter in abundance, are present in the rock, but the latter mineral at least has no immediate relation with either of the manifestations. Another instance of two areas of micropegmatite of different degrees of fineness in juxtaposition was observed in Moy granite, Inverness-shire, where an area of fairly coarse micropegmatite was seen radiating from muscovite and biotite. A small roughly quadrangular white spot at its periphery in a different position of the nicols was observed to show an exceedingly fine micropegmatite. Microcline is present in this rock in sparing amount, but it does not occur in immediate relation to these particular areas. These observations in themselves suggest different periods of origin for the two forms of concomitant micropegmatite. They manifestly, when taken in conjunction with the generalizations as to the periods of appearance of the different forms of the B type of micropegmatite already made, also suggest the further question as to whether the mineral microcline might not be associated with changes at some distance from the locus of its development. We shall subsequently see that some reason exists for concluding that such action may possibly occur.

The C Type of Micropegmatite.

The C type of micropegmatite is of limited occurrence in the true granites, and its presence in these is difficult of determination as it is associated in a number of cases with micrograniticstructure, which tends to obscure it and prevent its determination with absolute certainty. In considering this manifestation, regard must also be had to the minute micropegmatised plagioclases which have been pushed aside by the advancing orthoclases and microclines, and which serve materially to complicate the case. These minute plagioclases radiate into the orthoclases and microclines on one side, and are backed up on the other by microgranitic or micropegmatitic areas of the C type (?), or a mixture of the two together. When all this is discounted the question arises if anything of the C type of micropegmatite remains to be described in the true granites. The only granite in which it is undoubtedly present is the Corrennie granite, and it is also present in the Granophyres of Skye. In the granite it is associated with some microgranite, and occasional small felspars inside the microgranitic areas show micropegmatite structure, but that can hardly be considered a typical manifestation of the C type of micropegmatite. Microgranite, on the other hand, is typically present in some of the specimens of Ben Nevis granite, where it forms a matrix in which crystals of hornblende, biotite, plagioclase, and orthoclase are embedded. The orthoclases and occasionally the plagioclases show small marginal inset quartz grains, which are sometimes wholly, sometimes only partially, surrounded by the felspar. In one or two instances they have been seen to form distinct zones around the margins of the felspars a little way in from their edges. The exact counterpart of this is seen in one of the slides of Longmanhill granite from near Banff, where there is no hornblende, but where microcline is present in small amount. In this respect it also differs from the Ben Nevis rock. In the Longmanhill granite idiomorphic quartz crystals have been observed with an insetting of small felspars, some of them showing microcline structure, parallel to and at some distance from the margin of the quartz grains. These two cases indicate different relations in the quartz and orthoclase as regards their crystallization periods, the explanation of which will come up later.

Micrographic areas are also seen in Avochie granite, where they conform more or less to the pattern of this manifestation as seen in Corrennie granite. With the exception of a few porphyritic orthoclases, which show in their structure more than one period of development, an irregular nucleus being surrounded by an external zone of fresher orthoclase. Microgranite also forms the bulk of a granite from Dalmunach, Knockando, Morayshire.

Micropegmatite of C Type in the Atypical Acid Rocks.

Micropegmatite of the C type is typically developed in the dyke and effusive rocks of the Acid series. The base of the porphyry of Boddam is composed of a micropegmatite so fine that it requires a high power to demonstrate its character. Of two fragments from the O. R. Cabrach, one shows a micropegmatite base, the other a sphærulitic. In the sphærulitic dyke from Broadford, Skye, the sphærulites have formed round small quartzes and felspars, while the intervening spaces are filled up with fine micropegmatite. A felsite from near Mintlaw, Aberdeenshire, shows a base which is partly microgranitic, partly micropegmatitic. A felsite fragment from the Trias of Elgin shows a very fine micropegmatite base, with porphyritic quartz grains sometimes composite, and one of which was seen to present the well-known arrangement of the quartz characteristic of micropegmatite aggregates without the usual supporting felspar, thus showing that the quartz may occasionally develop some time *before* the felspar in these aggregates, which in fact, as here illustrated, may not develop at all. Several slides from a peripheral rock of the Benachie mass, near Premnay, show a typical micropegmatite base, but without exception the finest micropegmatite of this type was discovered in a quartz felsite pebble from the O.R. near Fochabers. Felsite blocks scattered over the hill of Corinacy, Cabrach, show in part a microgranite, in part a micropegmatite base. Among the hornblendic rocks the only example found of the C type was in a glacial boulder in Morayshire about a mile to the N.W. of Elgin, the origin of which is unknown, so that the field relations of the parent rock are also unknown. It shows idiomorphic hornblendes set in a matrix of irregular quartz and orthoclase micropegmatite. The four sections from small felsite veins in Ben Cruachan granite are of much interest in this connection. These may be described in more or less detail.

(1) The largest, about 1½ inches in diameter, shows the A type of micropegmatite of the usual quartz orthoclase variety. The orthoclases occasionally show fine examples of the B type where they bound other orthoclases. This specimen has also yielded important points regarding the bearing of such veins on the production of metamorphism, and the relation of metamorphism to the development of micropegmatite of the B type in the contact rock. (2) A ½ inch vein shows only the merest fringe of radiating micropegmatite along the line of contact. It is sometimes interrupted and the rest of the vein is a pure microgranite. (3 and 4) Also ½ inch veins show a somewhat irregular narrow band of fine granular micropegmatite next the contact rock. This again grades into a fine radial micropegmatite, which towards the centre of the vein again becomes of the granular type. Towards the centres of the veins this tends to be replaced by islands of almost pure quartz. The margins of the veins are very well defined in all but the largest vein, where even under

the microscope it cannot be traced with any definiteness. These veins—the three last in particular—show that the conditions that determine the development of a micropegmatite base as against the conditions that determine a microgranitic base must be very finely drawn.

Conditions that Simulate Micropegmatite.

Where hornblende and biotite are both present in the same rock, it is not uncommon to find the hornblende invaded by very fine quartzes in the neighbourhood of the biotite. These give a "worm-eaten" appearance to the hornblende. Sometimes, however, the appearances are so regular as to simulate a micropegmatite. But generally the appearances are much less regular. Sometimes the biotite is invaded in a similar manner by quartz, and it is doubtful in some instances whether it should not then be classified as micropegmatite. An example of this character was observed in the diorite of Hunthill, where a corroded augite was seen occupying the centre of a plate of biotite. From the central corroded augite trabeculæ of quartz and biotite were seen to pass out to the surrounding biotite. The quartz and biotite were as regularly intergrown as they are in a true micropegmatite, and I am not sure that the drawing of a distinction was warranted in this particular instance. The quartz associated with corroded hornblende is almost always of more irregular growth in instances of the secondary corrosion of hornblende by biotite. Another manifestation has also to be carefully distinguished from micropegmatite. This is a rather irregular dissemination of fine quartzes through hornblende, which however, in the absence of biotite, must be ascribed to the early development of quartz in association with hornblende on the lines previously described. Examples of this were observed in the Dalltullich rock already referred to. Biotite is practically absent from this rock, and is totally absent from many of the hornblende aggregates where this peculiarity is observed. As already described a true micropegmatite of quartz and hornblende does occur, so that there are evidently three conditions under which quartz and hornblende may be associated that closely resemble one another. These briefly stated are—(1) The early development of quartz in very fine grains in association with hornblende in which it has originally been dissolved; (2) The association of quartz with hornblende which has undergone corrosion in connection with the development of biotite. (3) A true micropegmatite of quartz and hornblende.

Theoretical Considerations.

I shall now endeavour to reduce the various observations recorded and classified in the foregoing part of this paper to some system by attempting, however imperfectly, to explain the processes by which the different phenomena have been brought about. In this connection it will be preferable to consider deviations from the normal order of crystallization, and the manifestations of micropegmatite as concomitants—and all but necessary concomitants—of a single process—the solidification of a granite magma. As already shown, it is exceptional to find among the granites of the North of Scotland a granite without deviations from the normal order of crystallization. It is also exceptional to find a granite without some form of micropegmatite; so that a granite without either of these manifestations must really typify the exceptional case and by implication have taken origin under conditions which are really abnormal. How far and in what direction the conditions of development in such case have deviated from the normal conditions exhibited by the majority of the granites, will be one of the most interesting questions that will come up for discussion.

Broadly it may be said that all the phenomena that have been described in an earlier part of this paper are most readily explained on the theory of *the origin of granite by crystallization from solution*, or on that theory aided by certain definite principles, which are of the nature of necessary deductions from that theory. The process of crystallisation, it may be premised, is not at all points a progressive one. At certain well defined stages, what look like reversions of the process come in as normal occurrences—at least they are relatively of so frequent occurrence that they must *ab initio* be considered as the real normal occurrences. These retrogressive processes partake of the nature of resolution of parts which had already become solid. They undoubtedly at first sight appear to complicate, but do not in any way interfere with the general scheme of crystallization. There are in addition one or two other developments, which may be broadly interpreted as resorptive processes, but which embrace in addition a certain amount of chemical change. These, however, appear to depend for their operation on much the same cause as those just referred to, but are of such importance as to call for separate treatment. The order of crystallization, as we have already seen, depends in some instances on composition, and it will become evident on further discussion that composition, broadly interpreted, is a predisposing element in all or almost all cases.

Silica-Saturated Solutions.

In order to present the problem as clearly and intelligibly as possible, it will be preferable to start with one or two general points regarding silica-saturated magmatic solutions.

It is well known that the presence of water at a high temperature facilitates the solution of quartz. Imagine a magma saturated with quartz in virtue of the quantity of water it contains, and that quartz, water, and magma generally are at a temperature and pressure just sufficient to maintain a condition of equilibrium. If the temperature is now reduced, part of the quartz will fall out of solution; and should the temperature be reduced below the critical temperature of water, that would also separate in liquid form. If, on the other hand, in the same magma, the temperature of equilibrium being maintained, the proportion of water is reduced, as for example by escape at a volcanic vent or by its being used up in the formation of hydrated minerals such as biotite, muscovite, epidote, or allanite, or in any other way that may be possible, a proportional quantity of the quartz will fall out of solution and appear in crystalline form. This simple case in all probability covers the case of some classes of igneous rocks, where quartz appears earlier in the scheme of crystallization than orthoclase, or in some cases it may be even than plagioclase. Such is seen in some volcanic and dyke rocks of the acid group, that is to say in rocks of similar composition to granite, but where they have consolidated on the surface or at relatively less depth in the earth's crust than granite, in other words under conditions that have permitted a relatively freer discharge of aqueous vapour.

Take another more complex case. Starting with a silica-saturated magma and supposing hornblende and quartz, if necessary, are added till saturation is reached, we have now hornblende, quartz, and water all present and in equilibrium at definite temperature and pressure. Our observations would indicate that the mere presence of hornblende facilitates the solution of quartz. Hence in our hypothetical magma a descent of the temperature would be accompanied by the separation of hornblende followed by as much of the quartz as was previously held in solution by the hornblende originally in solution. The quartz in this case will appear at an abnormally early period in the scheme of crystallization, and will explain the early appearance of quartz in association with hornblende as observed in many hornblendic granites. Similar reasoning would apply to the early appearance of orthoclase, and plagioclase, which show a similar association with hornblende in many hornblendic granites.

To go a little more fully into this part of the scheme of crystallization of a hornblendic granite, it is evident, from the frequency with which quartz, orthoclase, and plagioclase appear in these rocks at an early stage of the crystallization in association with hornblende, that something of the nature of a general law obtains as to this relation, and the solubility of these substances to some extent in the hornblende seems to be the readiest and easiest way to explain their occurrence in this association. The relative quantities of these substances appearing in this connection will naturally depend on the quantity of hornblende present, which at this stage may be considered in the light of solvent of these substances. If hornblende were in marked excess it would separate at first on the necessary reduction of the temperature, and for some little time as pure hornblende unmixed with these minerals. At length a stage would be reached where the remaining hornblende would no longer be sufficient to dissolve all the quartz, and a proportion of it would therefore fall out of solution, and from that point the hornblende and quartz would separate in definitely related quantities. The product would now in fact be of the same character as regards composition as a cryohydrate mixture, and would continue to separate in such definitely related quantities up to the exhaustion of the hornblende. That this is probable is shown by the relation of the quartz and hornblende. In some hornblende groups no quartz appears with the hornblende, which would indicate that the hornblende at first existed in excess and separated for a time by itself in the pure state before the stage of cryohydrate composition was reached. Then small crystals of hornblende appear surrounded by quartz, indicating the beginning of the separation of the cryohydrate mixture. A sort of rough alternation of hornblende and quartz will now occur. Thus a little hornblende separates; this reduces the quantity of hornblende present below the quantity necessary to keep all the quartz in solution, so that a relative quantity of quartz must separate. This probably oversteps the stage of equilibrium, and a little more quartz than is necessary separates, so that a little more hornblende must separate again, and so on, till the hornblende, in virtue of the gradually lessening temperature, reaches the stage of exhaustion, and the separation of both hornblende and quartz closes. The continued lowering of the temperature, even granting the temporary establishment of equilibrium, would itself eventually bring about the same result. The same reasoning would apply to the relations of hornblende and orthoclase, and to the relations of hornblende and plagioclase, and give rise to a similar association of these minerals with hornblende, as is indeed frequently observed. A question will arise as to the possibility of interactions arising between the substances originally dissolved in the hornblende when all are present, as to how far they may interfere with and modify each other's solubility and separation from solution as compared with what might be expected to occur if they were present singly or in pairs. No evidence from the observational side, however, has been obtained bearing on these points, and the general inference is that the effect would probably be insignificant.

It has already been indicated on observational grounds, that the minerals quartz, orthoclase, and plagioclase have separated in this connection in the order named. This is an order which is the inverse of that obtaining in the normal order of crystallization in the final stages of crystallization of a granite. More than one theoretical reason could be given for this. Their appearance is in the order of their melting-points. A solvent of this nature might be expected to deposit its solutes, though considerably below their natural melting-points, still in order of these melting-points. Again, cryohydrate mixtures begin to appear at definite temperatures. These temperatures have fairly definite relations to the crystallizing points of the two substances. These may be put down as somewhat below a rough mean of the two crystallizing points. As the crystallizing points of quartz and hornblende together are greater than those of orthoclase and hornblende together, the cryohydrate of the former pair will appear before that of the latter pair. For a similar reason the cryohydrate of orthoclase and hornblende will appear before that of plagioclase and hornblende. So far the hornblendic section of the scheme of crystallization appears to fall into line very easily and naturally on the theory of solution of these substances in hornblende in its originally liquid state.

The study of solutions of simple inorganic salts of low melting-points, in aqueous solution, leads us to believe that the following results would be observed under the conditions now to be described :—

A magma containing a definite quantity of water would naturally be found to dissolve, at a certain temperature and pressure, a certain proportion of quartz, but with continued rise of temperature, the pressure remaining constant, a point would eventually be reached where no more quartz would dissolve, or dissolve so slowly with increase of temperature as to be practically insignificant. Finally, however, on the temperature reaching the actual melting-point of quartz, it would be found to suddenly pass into the liquid state, and probably not appear specifically different from a true solution—to an indefinite amount. In this case one part of the liquid product would be kept in solution by pure dry heat—the temperature of fusion; the other part by the high temperature in conjunction with the solvent action of water. On lowering the temperature below the melting-point of quartz, the former part would separate at once, but the latter would continue in solution, down to a temperature correlative with the relative proportions of quartz and water present, below which crystallization would again take place. A natural magma containing quartz kept in a condition of liquidity, partly by a temperature in excess of the melting-point of quartz, partly by the presence of water, would, on cooling, deposit its quartz at two very definite periods—one early, at a temperature just under the melting-point of quartz; another later, when a further descent of temperature or loss of aqueous vapour rendered the magma incapable of retaining the remaining quartz any longer in solution. Such a case is probably capable of explaining some of the facts observed in relation to the two periods of separation of quartz observed in some igneous rocks.

But without going so far afield as the actual melting-point of quartz under purely dry heat, I think it is possible to account for several anomalous appearances of quartz, and in particular of some of its earlier manifestations in hornblendic granites, on quite other lines. Up to a certain grade of temperature, depending on the quantity present in a given case, water may be looked on as the solvent, and quartz, and to a variable extent other minerals also may be expected to pass into solution in virtue simply of the amount of water present in the magma. Beyond this temperature, and when the water present has ceased to have any further effect in bringing further quantities of quartz and its associated minerals into solution, it would appear that other substances may take up the rôle of solvent and continue to bring further quantities of quartz and other minerals into solution. That hornblende for one takes up this function is, I think, very probable. If so, the fact would very neatly explain the association of quartz, orthoclase, and plagioclase with hornblende in the early stages of crystallization of hornblendic granites. That other minerals may play the rôle of solvent is, I think, likely, but the evidence may not always be so complete as in the case of hornblende. The evidence, however, is fairly strong in the case of biotite, where there is a strong tendency for quartz to occur both as inclusions inside that mineral as well as in definite grains in juxtaposition to it outside, as has been observed and recorded in a number of granites, as already stated.

Under such conditions, it might be thought on cursory reflection that all hornblendic granites ought to show inclusions of quartz, orthoclase, and plagioclase in the hornblende in every instance, and in like manner that all biotite-bearing granites ought also to show them in every instance also. The question will naturally be asked—if quartz, orthoclase, and plagioclase are soluble in hornblende and biotite, why do not these minerals appear as inclusions in hornblende and biotite in every instance? Where there is excess of solvent hornblende or biotite, manifestly this excess will crystallize out, without showing any inclusions of these minerals; only with the last portions of these substances to crystallize, and then only in the case of highly silicated magmas, would the quartz, orthoclase, and plagioclase tend to appear with the hornblende and biotite. Should there be present in the magma sufficient water to act as solvent to all the quartz, orthoclase, and plagioclase, manifestly this would tend to take up, to re-dissolve these substances, or otherwise prevent their separation with the hornblende and biotite. These would therefore, in such circumstances, continue to crystallize up to the point of exhaustion of the magma as pure aggregates of hornblende and biotite; that is to say, they would not be mixed with quartz, orthoclase, and plagioclase of the early crystallization. The view just enunciated will serve to explain some of the differences that obtain in granites in respect to the presence or absence of these inclusions in the hornblende and biotite.

Inclusions in Sphene.

The same three minerals have, as before stated, been observed as inclusions in sphene, and the question will arise as to whether the same explanation may not hold good as in the case of their association with hornblende and biotite. The association of single units of quartz, orthoclase, and plagioclase as inclusions in sphene suggests rather the crystallization of sphene round pre-existing nuclei of these minerals, these nuclei having presumably appeared in connection with the separation of the hornblende on the lines just indicated. The fact that the orthoclase in sphene in all the observed instances appears in hazy rounded grains, is suggestive of the operation of some resorptive process having taken place in the interval. Such resorptive processes, it will be shown, are of frequent occurrence during the crystallization of a granitic magma. Cases, however, occur where the appearances point no less strongly to the conclusion that the presence of sphene, like that of hornblende and biotite, promotes the solution of quartz at least, and it is not unlikely that the same is true of orthoclase and plagioclase also. An example of this intimate relation between sphene and quartz has been observed in Stratherric granite.

The Escape or Absorption of Water in Relation to the Separation of Quartz.

The escape or absorption of water has no doubt had an important bearing on the relative order of the separation of the various minerals from a granitic magma. Any condition that reduces or potentially reduces the water content of a magma is likely to affect the crystallization of quartz in particular, and it may be, though to a less extent, of orthoclase and plagioclase also. The tendency of quartz to occur in close association with biotite, which has been very frequently noted in these granites, is in all probability due in part to the fact that biotite is a hydrated mineral. The separation of biotite from a quartz-saturated magma, by the mere fact of its reducing the water content of the magma by the quantity of water necessary to the formation of the biotite, is an efficient cause of the separation of a proportional quantity of quartz. Thus quartz appears both as inclusions in the biotite and as separate quartz grains in its immediate neighbourhood. The quantity of quartz appearing in this connection would be in direct relation to the amount of water used up in the formation of the biotite, and consequently in direct relation to the quantity of biotite also. In the corrosion of hornblende, which is frequently seen in connection with the crystallization of biotite, quartz also makes its appearance, and here also it apparently owes its origin to the same cause, though another element comes in to accentuate the result in this case. This is the fact that hornblende is a more highly silicated compound than biotite, and the excess of silica appears as part of the free quartz associated with the biotite-corroded hornblendes. The effect of the change of hornblende into biotite may be broadly typified by chemical equation, the latter mineral being supposed to take up the necessary water, potash, and alumima from the still liquid portion of the magma, and to return lime to it thus:—

$$\frac{\text{Hornblende}}{FeO,CaO,(MgO)_2,(SiO_2)_4} + \frac{\text{From Magma}}{K_2O + Al_2O_3 + H_2O} =$$

$$\frac{\text{Biotite}}{K_2O,(MgO,FeO)Al_2O_3Fe_2O_3,(SiO_2)_3,H_2O} +$$

$$SiO_2 + [CaO \text{ into Magma} + MgO \text{ Excess}].$$

This equation shows the liberation of silica as a direct result of the chemical change. The taking up of water by the biotite from the magma in order to complete its molecule would also reduce the water content of the magma, and thus give rise to a further separation of quartz, to an extent which would also be correlative to the amount of biotite formed. Thus it would appear that in the corrosion of hornblende by biotite in a silica-saturated magma the appearance of quartz is due to two independent reactions.

There appears to be little doubt that the formation of hydrated minerals frequently leads to the separation of quartz. This has been observed in this research in connection with the occurrence of epidote in Hildesay granite, in which quartz invariably appears as inclusions in the epidote which characterises that granite. The association of quartz and zoisite is also a case in point, and the following bulk analysis, which was made several years ago in another connection from an unpicked specimen of zoisite from Garve, suggests a quantitative relation between the two minerals

Analysis of Zoisite from Garve, Ross-shire.

SiO_2	55·02
Al_2O_3	20·46
Fe_2O_3	2·88
CaO	16·66
MgO	·31
K_2O	·41
Na_2O	1·34
H_2O	1·95
	100·37

The result of this analysis corresponds very closely to the formula :—

$$(Al_2O_3)_2, (CaO)_3, (SiO_2)_9, H_2O.$$

From the analysis of pure zoisite the formula should be—

$$(Al_2O_3)_3, (CaO)_4, (SiO_2)_6, H_2O.$$

Comparison of these two formulæ suggests the possibility of the breaking down of a higher silicated compound into ziosite and silica, or the separation of silica, as the result of the absorption of water necessary to form the zoisite molecule. Hence the amount of silica separating is strictly proportional to the zoisite formed. Allanite is another hydrated mineral which appears early in the scheme of crystallization, and has repeatedly been observed in this research. No instance, however, has been noted where it was found associated with the separation of quartz. The relatively early period at which allanite appears, always earlier than epidote, in which it is frequently included (*e.g.*, in Hildesay granite), has probably some bearing on the non-appearance of quartz in this instance.

Inclusions in Biotite.

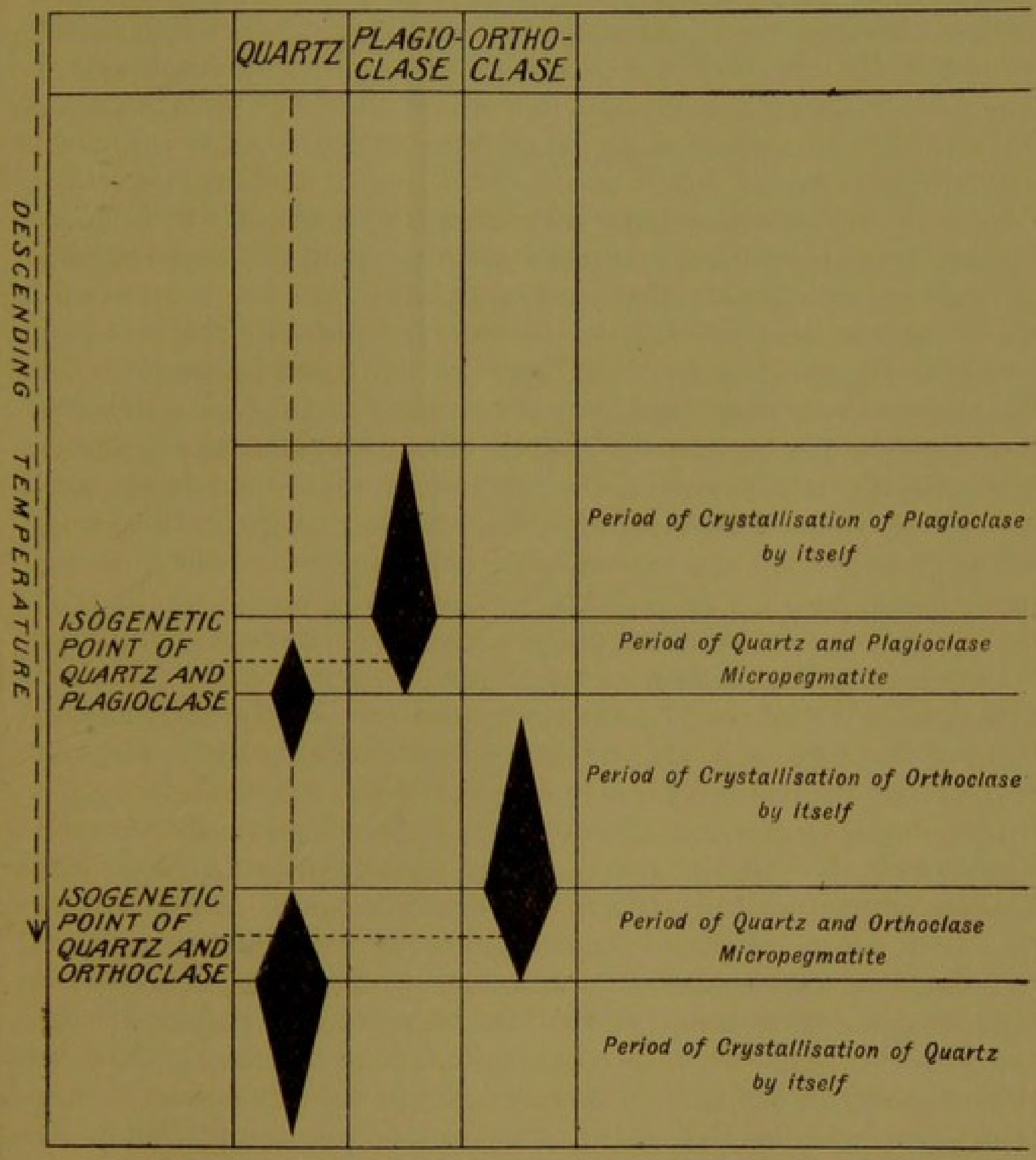
The inclusions in biotite are usually quartz, orthoclase, and plagioclase. The same explanation, as already indicated, applies to their appearance here, as in the case of hornblende. Small sphenes are not infrequent in biotite, and doubtless owe their origin to the continued solubility, in a small degree, of sphene at relatively low temperatures.

The Order of Crystallization of Plagioclase, Orthoclase, and Quartz, and their Relation to the A-Type of Micropegmatite.

The normal order of crystallization of the three minerals, plagioclase, orthoclase, and quartz, is in the order named. As we have seen, however, deviations are frequent and are entirely due to the marked tendency of quartz to deviate from its normal position in the scheme of crystallization. The more acid—that is the more highly saturated with silica a magma becomes—the greater is its tendency to show abnormalities in regard to the order of appearance of quartz. It may be said that the greater the excess of free silica in the magma, the greater is the tendency for quartz to be thrown forward in the scheme of crystallization. This peculiarity, however, it shows in common with saturated, or approximately saturated, aqueous solutions of simple salts generally. As a consequence the period of crystallization of quartz comes to overlap the period of crystallization of orthoclase, and in the most highly saturated magmas it even tends to overlap to some extent the period of crystallization of the plagioclase also. Of this we have seen several examples—for instance, in Ben Nevis granite. The instances where the period of crystallization of quartz has invaded the period of crystallization of the plagioclase are no doubt relatively rare; the instances, on the other hand, where it has invaded the period of crystallization of the orthoclase are relatively frequent. In addition to the atypical occurrences of quartz included in orthoclase, all the instances of occurrence of the quartz-orthoclase variety of the A type of micropegmatite are examples of this invasion of the orthoclase period by the quartz. Whether we consider that this has resulted because the water present has failed earlier and at a relatively higher temperature than usual to keep the excess of quartz in solution, or that the orthoclase has failed, or that the water and the orthoclase together have failed, is on the whole immaterial. The result in any case is really due to a relative or absolute excess of quartz in the original magma, thus coming back again to the question of initial composition of the magma. We may conceive the magma at this stage as containing two substances whose periods of crystallization overlap, and both of which are in the act of crystallizing. One—the orthoclase—has reached a certain stage before the other—the quartz—

has commenced to separate at all. The separation of the two minerals after a certain interval proceeds side by side at unequal rates—the orthoclase finally dying away as the quartz increases in its tendency to separate. It will readily be seen that if a solution is depositing two substances, of which the tendency for the one is steadily to decrease in amount as the other is increasing in amount, at a certain stage must come a period when the solution will show an equal tendency to deposit both substances. At this point the solution may be said to be isogenetic as regards the two substances, *i.e.* it shows an equal tendency to deposit the two substances. Now, our observations go to show that from some distance above the isogenetic point up to the exhaustion of the solution of the substance which was the first to start crystallizing, the two substances will tend to appear intergrown as micropegmatite, and the substance which was the last to start crystallizing will continue to crystallize after the solution is exhausted of the other, in its normal place in the scheme of crystallization. This is simply putting in general terms the observations that have been made time and again on manifestations of the A type of micropegmatite. We may illustrate the points by a reference to the conditions obtaining in some sections of Ben Nevis granite. In some specimens of this granite we have two isogenetic points—one for quartz and plagioclase and another for quartz and orthoclase. The examples from Ben Nevis granite show a tendency to a passage from the crystallization of plagioclase to the crystallization of quartz. This is seen in outgrowths of micropegmatite of the A type from the edges of some of the plagioclases. The quartz grains near the border of the plagioclases are small and approximately equal to the plagioclase areas, and are found to extinguish simultaneously; but as we trace them outwards the quartz areas get progressively larger and the plagioclase areas smaller. There is thus a passage from isogenesis near the crystal border to anisogenesis towards the periphery, the quartz finally becoming continuous with the general quartz of the rock matrix. In other instances in the same granite we have the same facts illustrated in the case of orthoclase and quartz. Again, in the case of a specimen of the A type of micropegmatite from Abriachan granite, the quartz grains become progressively larger from one side of a single orthoclase crystal towards the other. In Benrinnes granite also, in a large twin orthoclase showing micropegmatite of the A type, the quartzes were seen to become progressively larger when traced outwards on each side from the twinning plane. The periods of crystallization of plagioclase, orthoclase, and quartz, with the period of development of the A type of micropegmatite, may be represented schematically as below :—

The vertical dark bands represent the crystallizing periods of quartz, orthoclase, and plagioclase as the temperature descends, the anomalous early crystallization of quartz being represented



Scheme of Crystallisation of Quartz, Orthoclase, and Plagioclase as seen in Ben Nevis Granite.

by a narrow interrupted line. The diagram is otherwise self-interpreting.

I am of opinion that all cases of genuine micropegmatite of the A type may be interpreted on the same lines, whether these are of the ordinary quartz-orthoclase, quartz-plagioclase, or quartz-hornblende type. In this research the quartz-orthoclase type has bulked most largely, and may be considered the commonest form and the one most likely to occur in typical form.

It would appear that the quartz-orthoclase micropegmatite of the A type is a special case of the ordinary single quartz-inclusion in an orthoclase crystal, and due to a special phase of the same set of conditions. The single included crystal is the early phase, the micropegmatite a later phase of the development. Where the quartz grains included in orthoclase are rounded, the origin of the quartz at an earlier stage is premised, resorption having taken place in the interval; but such instances can hardly be classified as belonging to the A type of micropegmatite. Again, cases occur which show a transition stage. These are where orthoclases occur showing a number of included quartz grains, which extinguish simultaneously, along with one or two grains that extinguish separately. Such a combination has been seen in a number of granites, and notably in Knockando granite, which is a local variety of the Benrinnes rock. The Benrinnes rock itself shows the A type of micropegmatite very frequently, and, as already stated, also a form where the quartz included in the orthoclase extinguishes somewhat irregularly, though in places with some approach to micropegmatite structure. This arrangement has previously been spoken of as "spongiform orthoclase." As regards the causes of this early appearance of quartz in association with orthoclase, the predominating condition is of course hyperacidity. What the particular condition may be that breaks down and permits the early separation of the quartz, it may be impossible to decide with certainty. It may be deficiency of solvent water in the magma; it may be deficiency of orthoclase, the presence of which no doubt has some bearing on the solubility of quartz; but all the evidence we have goes to show that it must be very insignificant. It may be a lowering of pressure. Quartz and orthoclase [1] are substances whose formation is accompanied by an increase of volume, which means that they would become solid at lower temperatures under increase of pressure. But if this be so, the effect of pressure must be much less marked in the case of quartz than in the case of orthoclase. On the whole, the effect of pressure, if we are to follow the analogy of simple inorganic salts, is probably really insignificant. This leaves us with deficiency of aqueous solvent in conjunction with excessive acidity as the chief determining cause of the early appearance of quartz in this association. The same condition when carried to its limit probably covers all the manifestations of the early appearance of quartz, and of the A type of micropegmatite as well.

We have now considered two different periods of abnormal quartz formation—one with hornblende, the other with orthoclase. The product in the former case is of the nature of a cryohydrate;

[1] Löwinson-Lessing's law.

in the latter it is a micropegmatite. In the former case, solvent and solute become solid simultaneously; in the latter two solutes separate simultaneously in correlated quantities, thereby giving rise to a symmetrical structure of fairly definite composition. But, manifestly, absolute uniformity of composition cannot be predicated of these aggregates.

The B Type of Micropegmatite.

Before proceeding to discuss the cause or causes of the manifestations of the B type of micropegmatite it will be convenient to discuss a few preliminary propositions, which will be essential to the complete understanding of the processes concerned in its development. The first of these propositions is—*That in the areas in which micropegmatite of this type is now observed, some liquid, the last remaining traces of the original magma, continued to be present up to the time immediately preceding the development of the micropegmatite*—and for the following reasons :—

(1) The manifestations in a majority of instances take the form of rounded or corroded masses of plagioclase-felspar, wholly or partially embedded in orthoclase or microcline, and showing the micropegmatite structure around their margins—more particularly in directions across and between their twin lamellæ, as would naturally tend to be the case, if a corrosional liquid were circulating around them.

(2) The radial arrangement of the quartz in the centric manifestations suggests action such as might be ascribed to a liquid spreading from a centre.

(3) The occurrence of areas of micropegmatite at points where a number of crystals meet, suggests the existence at these points of original lacunæ filled with liquid at a period after the surrounding minerals had crystallized.

(4) Irregular branching lines of micropegmatite, extending between and among the surrounding crystals, points to the conclusion that a liquid circulated along these lines after the general crystallization was wellnigh finished.

(5) Outgrowths of micropegmatite from otherwise nearly symmetrical crystals, and the sweeping of such outgrowths around and between other crystals as has sometimes been observed, are suggestive of a certain degree of liquidity or viscosity at a stage subsequent to the period of development of the crystals of which they are outgrowths.

(6) The generalization as to the different periods of appearance of this form of micropegmatite, which has already been made, indicates periods in the process of crystallization, when larger or smaller quantities of liquid according to the particular period would naturally remain unsolidified.

The evidence is on the whole fairly conclusive that some part of the original magma remained unsolidified up to the period immediately preceding the appearance of the micropegmatite, and the question will naturally arise: What was the composition of the portion still remaining liquid? This probably was not constant. No doubt it would vary to some extent with the stage at which crystallization had arrived. Some indication is from time to time afforded by a study of the minerals that have subsequently crystallized out in the micropegmatite areas. It is evident that it has always contained quartz, as quartz is necessary to the formation of the micropegmatite. At other times it evidently contained orthoclase. This is indicated in Pl. XXVIII., Fig. 8. At other times a narrow band of orthoclase is seen between two plagioclases which show local areas of micropegmatite, or again, a central orthoclase is bounded at both ends by plagiocases showing extensive micropegmatite. Sometimes central orthoclase extending between the ends of two plagioclases, which show the characteristic change, exhibits a central quartz grain of some size. This quartz probably indicates a residuum from the original attacking liquid after the separation from it of the orthoclase it originally contained. Such residual quartz grains are not uncommon in such areas, but are never very large. They often appear as a central quartz grain rather larger than the others on the micropegmatised end of a plagioclase felspar, and form centres from which the rest of the quartz of the micropegmatite, without actually being continuous with it, appears to radiate. In such cases the micropegmatite is always of a high grade. Microcline, again, is sometimes seen under conditions which suggest that it has crystallized from the liquid of the associated micropegmatite area. Such cases have been observed in Avochie granite and also in Kinsteary granite. In some cases the liquid remaining unconsolidated just before the development of micropegmatite must have been exceedingly small in amount, and in many cases have been limited in composition almost if not altogether to quartz. In this connection, it may be noted that, apart from the quartz subsequently appearing as an essential part of the micropegmatite, quartz, unlike orthoclase and microcline, has taken very little part as a functional agent in the actual development of micropegmatite. Though it has been observed on one or two occasions, quartz bounding an area of micropegmatite is rare. Quartz radiating from a definite quartz grain into and showing continuity with the quartz of a micropegmatite area is rarer still. One quartz included in orthoclase, showing this character, was seen in Hildesay granite, though it could hardly be considered a typical example. The general inertness of quartz in relation to the active development of micropegmatite is also shown in the fact that on tracing the boundaries of an orthoclase, which shows a micropegmatite edging, the micropegmatite has been frequently seen to terminate abruptly at a point where quartz begins to bound it, remaining absent opposite the quartz, and in some cases resuming again where the quartz boundary ceased. Typical examples have been observed in Peterhead granite.

Another question will now arise out of the two foregoing conclusions. Given the fact that some liquid magma remained just up to the period immediately preceding the development of micropegmatite, given also that this liquid contained in all probability the elements of orthoclase, sometimes the elements of microcline, and for a certainty in all cases quartz, what was its particular rôle in the development of the micropegmatite which subsequently appeared ?

It has been customary to speak of certain corrosional processes as taking place during the crystallization of granites and diorites, particularly with regard to the latter, where the action of biotite in relation to the changes that have taken place in hornblende has been spoken of as an " action of corrosion."[1] Without for the present raising the question whether what remained of the liquid magma at this stage could exercise an action of corrosion on the felspars which had previously crystallized from it, it will be necessary in the first instance to take up the question of what is meant by " an action of corrosion." In this connection the following general definitions may be made. Corrosion may be taken as meaning the passing of substances from the solid to the liquid state in virtue of some chemical action between the solid and the attacking liquid, the latter being usually considered the aggressor. Solution, on the other hand, should be restricted to simple liquefaction by heat or pure solvent action, without the intervention of any chemical action whatever; while " resorption," a term sometimes used in connection with the crystallization of igneous magmas, might very well be used to cover both cases; that is to say, it may be considered equally applicable to the disappearance in whole or in part of minerals already crystallized, whether such disapperance is to be attributed to part solution, or solution aided by chemical change.

[1] See interesting summary of views on this point by J. S. Flett in Geological Survey Memoirs, " The Geology of Lower Strathspey," pp. 39 and 40.

We shall find that all three terms find fitting application to different processes that have taken place during the passage of a granitic magma from its initial stage of perfect liquidity to its final stage of total solidity. The question that at present arises is—Which of these terms is applicable to the stage that preceded the development of micropegmatite ?

When one considers that the substances remaining in solution under any circumstances previous to the development of micropegmatite must be limited to orthoclase, microcline, and quartz, and that the substances on which they react in the solid state are limited to plagioclase, orthoclase, and possibly in rare instances microcline, it will be seen that the scope for chemical action is strictly limited; and, though chemical action cannot be absolutely discounted, it must have played a very limited rôle in the changes that led up to the development of micropegmatite; and, granting that such action was an element in the case, it was not calculated to be of sufficient intensity to bring about the observed results. If chemical action then was absent or insufficient, what other agencies may have been present? After studying the question from all points of view, I have come to the conclusion that heat alone was a sufficient and at the same time the most probable cause. What was the source of heat ? It means an accession of heat after most of the minerals have crystallized out—a return to a higher grade of temperature after a certain fall. How was this brought about ? Was it due to an external or an internal cause ? I hold strongly to the view that this accession of heat was due to the crystallizing of orthoclase, and at a somewhat later stage to the crystallization of microcline also, should it happen to be present. It must be evident on inspection of a table of melting points of the various minerals usually present in a granite, that they crystallize very nearly in an order which is the inverse of the order of their melting points. In that case the later crystallizing minerals, such as plagioclase, orthoclase, microcline, and quartz, must have crystallized at temperatures considerably below their melting points. From the analogy of simple salts crystallizing from aqueous solution, there is very good reason for concluding that these temperatures were not necessarily, or with a degree of probability even remotely, constant. That, however, for our present purpose is immaterial. The most important consideration is, that a substance crystallizing below its melting point, no matter how far below its melting point crystallization may begin, theoretically liberates in the act of crystallizing as much heat as is necessary to again raise it to its melting point. This is probably seldom realised in actuality. Questions of specific heat, of latent heat, of expansion or contraction, in passing from the liquid to the solid state, come in to prevent the theoretical result being actually realised. One or two examples may be given of the behaviour of simple salts in crystallizing from aqueous solution. Thus the salt $Na_2S_2O_3$, $5H_2O$ sodium hyposulphate melts in its water of crystallization at a temperature of 45° C. (Roscoe). My determinations have been nearer 47° C. The solution may be cooled as low at least as -14° C. without crystallizing, though I saw it once start off apparently spontaneously at -4° C. At whatever temperature, however, crystallization is set up, the temperature speedily rises to 48° C., even when the quantity of melted salt experimented on is not more than 100 c.c., and remains close to that figure for more than an hour. The salt Na_2SO_4, $10H_2O$ (sulphate of soda) also melts in its water of crystallization at a temperature of 33° C. It may be cooled a long way below that temperature without crystallizing, and when crystallization is set up a temperature of 27° C. is reached. Here the temperature, as recorded by the thermometer, is considerably below the actual melting point. These two salts may be taken as typifying the results that may be expected in definite solutions of simple salts. With mixtures of salts the temperature is found to be reduced. Thus, if in the liquefied salt $Na_2S_2O_3$, $5H_2O$, nitre (KNO_3) be dissolved to saturation, the mixture may be cooled indefinitely without crystallizing, and on crystallization being set up a temperature of 37° C. is recorded. This latter example will show the effect of dilution with neutral substances on the temperature likely to be reached in mixtures of several substances. In granites each mineral as it crystallizes out would be diluted with all the other substances present along with it, so that the medium as a whole would not reach the melting temperature of the crystallizing mineral, but would of necessity reach a temperature which would evidently approximate more and more closely to that temperature as the proportion of that particular mineral was increased. Excluding questions of heat conservancy, latent and specific heat, and so on, if 50 per cent. of a mineral were present, it should, on crystallizing, other things being equal, manifestly raise the temperature of the medium to half way between the temperature at which crystallizing commenced and the melting temperature of the mineral. Theoretically, therefore, the medium as a whole could not possibly reach the melting-point of a particular mineral,—seeing it could only represent a percentage of that medium,—by the simple act of crystallizing of the mineral, but it might very well reach the melting-point of a mineral with a lower melting-point, which had previously crystallized out. This happens in the case of orthoclase and plagioclase. The former, according to Doelter, melts under ordinary pressures at

1175° C., the latter, plagioclase, at 1120° C. (oligoclase), 1110° (albite). The melting temperatures in a granitic magma will differ slightly from the temperatures just given on account of the pressure existing under such conditions, but the actual temperatures may be expected to preserve the same relations one to another under these conditions, and in the absence of any knowledge of what they really are, we may take the foregoing as our working figures. Suppose that orthoclase commences to crystallize at a temperature of 1080° C.—and all things considered it is probably oftener somewhat below that figure, and that there is 40 per cent. of orthoclase in the crystallizing medium, not by any means an extravagant estimate,—we might expect, *ceteris paribus*, that the crystallization of this amount of orthoclase would raise the temperature of the medium by 40 per cent. of the difference between 1080° and 1175° (its melting-point), or about 38°, that is to say the whole medium would reach the temperature of 1080°+38°, or 1118°, or considerably above the melting-point of albite, and just under the melting-point of oligoclase as above stated. This demonstrates the sufficiency of the heat of crystallization of orthoclase to raise the temperature of the medium to the melting-point of the previously separated plagioclases. If the medium reaches such a figure as that just indicated all the plagioclases present without exception would be attacked and partially liquefied, and this apparently has actually happened in the case of the specimens examined from Corrennie granite and the central boss of Benrinnes granite, as all the plagioclases without exception in these granites have subsequently developed micropegmatite. On first considering this point I was inclined to ascribe this peculiarity of these two granites to the action of some external source of heat acting on these masses as a whole. This in the circumstances would have been a somewhat gratuitous assumption. But the source of heat just indicated is evidently sufficient to account for the observed phenomena.

Again, if a small quantity of a salt in aqueous solution and freely exposed in a test-tube can preserve the heat it liberates on crystallizing practically undiminished for over an hour, what is to be expected in the case of a granitic magma where the dissipation of heat is at a minimum ? In the latter case heat conduction and convection would necessarily be very slow, so that in all likelihood the temperature, locally around the growing crystals, would for the time being reach, or all but reach, the melting-point of the mineral crystallizing. This would account for the partial solution of crystals of orthoclase by the heat liberated by the crystallization of the subsequently crystallizing orthoclases. The fact that the plagioclases show micropegmatisation in greatest degree bears out these theoretical considerations, their lower melting-point showing them to be capable of easier attack on a rise of temperature of the medium than the other felspars. That they are for most part only attacked locally, and in many cases even in the same granite not at all, would go to show that in the majority of instances the temperature only locally in the neighbourhood of growing orthoclase or microclines reached the actual melting-points of albite and oligoclase. The case of microcline, which according to Doelter has a somewhat lower melting-point (1155° C.) than orthoclase, presents on the whole somewhat more difficulty than the case of the orthoclase. With regard to the effect of the crystallization of microcline on the micropegmatization of plagioclase, the difficulty does not arise, as the melting-point of microcline is higher than that of any of the plagioclase felspars. Though no instance of its having affected the whole of the plagioclases in a granite, as has exceptionally happened in the case of orthoclase, has been observed, there is abundant evidence that it has affected a large proportion of them in a number of instances. The main difficulty is as to how the crystallization of microcline could possibly have affected the orthoclases, whose melting-point is some 20° higher. We have, however, to take into account the effect of pressure on the melting-point of the various minerals, and we have at present no knowledge of how pressure affects them individually. We have reason to believe that pressure lowers [1] the freezing-points of the different felspar species as they belong to the group of substances that increase in volume on formation, but as to how far the freezing-points of the different felspar species would be affected similarly we have no information. If the freezing-point of orthoclase was relatively more reduced by pressure than the freezing-point of microcline, we might in that case expect that the heat liberated by the crystallizing of microcline might possibly reach the melting-point of orthoclase. But it is well known that some minerals become soft and plastic at temperatures considerably below their actual melting-points, and this would probably be sufficient to permit of the subsequent development of micropegmatite in them. Instances of felspars showing micropegmatite from time to time occur which from their forms and general appearance suggest plasticity rather than actual liquidity, and the outgrowths which are sometimes seen bending round and passing between the neighbouring crystals also point strongly to the same inference. The few exceptional felspars showing micropegmatite which appear more or less completely surrounded by biotite call for only a passing

[1] Löwinson-Lessing's Law.

notice. The crystallization of felspars before biotite is exceptional. The melting-point of biotite (1130° C., Doelter) is higher than those of any of the plagioclases, so that there would be no difficulty for accounting for the change in their case on the theory that the heat of crystallization of the biotite was the efficient cause; but as we shall see later there is nothing to prevent the conduction of sufficient heat from a distance to effect the necessary change both in plagioclases and orthoclases; so that the agency of the biotite may very well be discounted.

The foregoing theory, I think, satisfactorily accounts for the necessary access of heat, without invoking the aid of chemical action, and without at the same time discounting it absolutely. The heat liberated by the crystallization of orthoclase and microcline appears to be quite sufficient by itself to account for the results observed.

It will now be necessary to indicate how the heat thus liberated operates. I think it will readily be seen that the presence of some remaining liquid is not an absolutely necessary condition of the theory, and in some cases the evidence goes to show that such liquid was extremely scanty. The quartz of the micropegmatite is the sole evidence of its existence in many cases. The heat evolved by the crystallizing felspars, I take it, acted through what liquid remained, and as by implication this liquid was in the act of being reduced in volume by the progress of crystallization, the growing felspars conveyed their heat to the gradually lessening liquid, which from that cause alone would tend to be raised to a higher grade of temperature. With the accession of heat the liquid would attack the felspars—the plagioclases and orthoclases, which had already become solidified, refusing their margins, and, if the action was sufficiently prolonged or intense, refusing them totally, so that they would actually disappear; and that this has really taken place in some cases cannot, I think, be doubted, as we have the remains of felspars—plagioclases in particular in all stages of attenuation up to the verge of total extinction. The after-stages of the evolution may now be traced. When the rise of temperature had reached its maximum, and completed its work of solution, the gradual descent of the temperature would eventually lead to resolidification of the areas of attack, and the process of resolidification appears to have taken place along very definite lines and with a degree of uniformity in the results that calls for special remark. The quartz appears in two forms in these areas: (1) In the form of small grains embedded in a felspar matrix, and (2) in fine curving, irregular, branching lines radiating from the supposed centre or surface of attack. Minute dots of quartz in other areas suggest that these lines or threads of quartz have been cut across in other sections. The idea of a process of leaching out of the plastic felspars having taken place during the process is frequently suggested by the appearances, and it might be supposed that the remaining attenuated substance of the crystals, left after the leaching process, had contracted along particular lines, and left fine fissures which had later been taken possession of by the infiltrating quartz. Indeed it is difficult to dismiss the view that this has been the actual line of development followed in some cases. It has always appeared that the uniformity of structure and consequent uniformity of composition require special explanation, and it is not easy to find an explanation that is in all respects adequate. The analogy of simple aqueous solutions would suggest that, while the process of liquefaction of the felspars was going on, the temperature of the liquid in contact with them would never reach above the melting-point of the particular felspar attacked, and could not possibly do so till it had been totally dissolved. This to some extent would account for the observed uniformity. But it may also have been due to much the same cause which produces uniformity in the product—locally a cryohydrate—when salt is brought in contact with excess of snow:—In other words the condition of equilibrium may have led up to the formation of a liquid which was practically uniform in composition. But was it uniform? The subsequent appearance of orthoclase, microcline, and quartz in the original areas of solution would indicate some exceptions, but in these exceptional cases we have reason to believe that these minerals were originally integral parts of the solution before it began to attack the felspars—the uniform product being thus made up of all in excess of the orthoclase, microcline, and the larger quartz grains of these areas, and would be derived in part from the felspars attacked, in part from the original liquid, and owe at least its essential quartz to the latter.

On the above theory the B type of micropegmatite finds adequate explanation as an effect of the heat of crystallization of later forming minerals of higher melting-points on earlier formed minerals of lower melting-points, and the amount of heat liberated in such case is perfectly adequate to produce the observed results, without calling in the aid of so-called corrosional or chemical action, between what remained of unconsolidated magma on the one side and the minerals which had already separated from it on the other. No very good reason can be given for assuming that a liquid from which substances had up to a certain stage been separating in crystalline form, should suddenly develop corrosional characters and proceed to attack the crystals, which had just separated from it. It is, in this instance at least, a pure *deus ex machina*, and has at best only a hypothetical existence. Of the liberation of heat by substances crystallizing below their melting-point there can be no question—it is a *vera causa*, and it is reasonable to suppose that it would have left traces of its action on structure. It is, so far as we have data available for calculation, of sufficient intensity for the work in hand, so that the assistance of other agencies is not required.

While the evidence of the work of the heat of crystallization is most manifest in the case of the felspars, and shows itself in the characteristic micropegmatite, it must not be supposed that the rôle of the heat liberated in the act of crystallization has been limited to these appearances. If a series of minerals is crystallizing out of a medium one after another, and all of them in turn below their normal melting-points, there will be a series of periods of evolution of heat, and much will depend on the amount in a particular case, whether sufficiently definite results will be produced to leave their final impress on the various minerals entering into the structure of the rock.

The Temperature Curves of a Cooling Granitic Magma.

If the temperature curve of a cooling granitic magma could be plotted, we should no doubt observe a curve of low gradients, corresponding to the general slowness of the rate of cooling, with definite and probably somewhat relatively sharp temporary rises of varying degree at definite points along its course, each curve corresponding to the crystallization of each particular mineral. We have not the requisite data for plotting such a curve with any degree of accuracy. We do not know sufficiently definitely the effect of pressure on the crystallizing or melting-points of the different minerals, though we have reason to believe that it raises the crystallizing points of ferromagnesian minerals and depresses the crystallizing points of the felspars. Supposing even that we knew the law of pressure in relation to the melting- and freezing-points of the various minerals, we have no very definite notion as to what pressures granites consolidate under. It probably varied from boss to boss. But, notwithstanding, I think it would be possible to plot a fairly representative curve of the temperature of a cooling granitic magma. As each mineral crystallized out there would be a temporary rise, perhaps with an exception in the case of hornblende, which would appear to begin to crystallize at a temperature in close proximity to its melting-point, if not actually above its melting-point at ordinary pressures. There would thus be very little rise in the case of hornblende. Towards the end of its period of crystallization, we have seen that under special conditions quartz, orthoclase, and plagioclase may fall out of solution along with it. This would be the time at which any access of heat, if it did occur, would manifest itself, and this would be sufficient to cause the observed effect on the orthoclases, which separated out at this period. A similar effect would be produced during the crystallization of the sphene, though as it is at all times relatively small in amount, the action in this case would be insignificant. One of the relatively greatest accesses of heat would be on the crystallization of biotite, of which the melting-point is, according to Doelter, 1130° C., or considerably higher than the melting-point of hornblende at ordinary pressures. It must therefore crystallize at least 40° C. below its ordinary melting-point, and the heat liberated on crystallization would be proportionate. The relatively limited quantities, however, in which biotite as a rule occurs, will modify the general rise of temperature of the mass, and the melting-point of hornblende may not be reached except occasionally and then only locally. Here again we have an efficient cause of the appearances frequently seen in connection with hornblende in the presence of biotite, and which have usually been ascribed to corrosional action at a later stage. No doubt the liquefaction of the hornblende is the first step in the change, and though quartz and biotite separate out in the areas that have been attacked, it does not necessarily follow that corrosional action was an essential part of the process in the first instance. The reaction has been already explained, and consists of a desilication of the hornblende molecule, with hydration of the product in the course of which silica is set free and biotite formed. Plagioclase next takes up the rôle of crystallization, but probably at some little interval after the biotite. The heat evolved in this instance is relatively small compared with that liberated by orthoclase in similar circumstances at a later stage, the melting-point of orthoclase being so much higher, but evidence of the action of both of these on biotite have been observed from time to time, and as might be expected, it is more marked in the case of orthoclase as typically seen in Ben Cruachan granite, where magnetite (?) in dark, irregular clots has been liberated from the attacked biotite by the crystallization of the felspars In other granites definite crystals of magnetite occur (Abriachan). Occasionally small colonies of magnetites appear in orthoclase (Peterhead), and are suggestive of their representing original biotite, of which they may be considered the only remaining traces. Here, I think, a certain amount of corrosional action must be admitted, in view of the marked change in the products, but the heat of crystallization of the plagioclase and orthoclase has no doubt markedly aided the reaction. The phenomena associated with the heat of crystallization of orthoclase and microcline developed in connection with plagioclase and orthoclase — or the manifestations of micropegmatite of the B type, have already been described, and call for no remark in this connection except that they are now shown to be only one of a series of changes developed in connection with the heat of crystallization of the several minerals present in a granite, and it will be seen that the series of such changes is fairly complete from stage to stage of the scheme of crystallization. Chemical action has no doubt in some instances contributed its share to the general result, but that on the whole has, I think, been relatively small.

General Resorptive Processes.

Evidence of resorptive processes other than those described above have been met with from time to time. These are confined to the rounded grains of quartz included most frequently in orthoclase, but also occasionally seen in other minerals. The particular period to which the changes they represent should be referred is doubtful, and may be synchronous with any of the foregoing changes. It will be evident that in the presence of a sufficiency of solvent water any temporary rise of temperature—and we have indicated the possibility of quite a number of such occurrences—would be accompanied by a certain amount of resorption of the previously separated quartz grains. Corrosion of orthoclase, as already indicated, has also been observed. In a specimen from Dalmunach, Elginshire, this corrosion of the orthoclase has been followed by subsequent growth of fresh orthoclase around the original corroded nuclei.

Sphene and Biotite.

A change that has been observed as taking place in the neighbourhood of biotites in some granites is associated with the development of small sphenes. This has been seen in Ben Cruachan granite and the Auchmair diorite, Cabrach. If oxide of titanium were normally present in biotite, the formation of sphene on decomposition of the biotite could be easily understood. In some instances it looks like a decomposition product, and is occasionally associated with iron oxides. In other cases the sphene is evidently original, but the particular method of its development in this connection is not very evident. The way in which it sometimes occurs as fringes to the biotites suggests crystallization around these as nuclei.

Hornblende and Biotite in relation to B Type of Micropegmatite.

It has been noted that areas of micropegmatite of the B type tend to develop in orthoclase in areas in close proximity to hornblende and biotite, particularly the latter. This is ascribed to the operation of some principle of heat conservancy, in virtue of which the temperature tends to rise to a higher grade in the neighbourhood of these minerals. It is not a case of the remaining liquid portion of the magma finding its way more easily along and between the surfaces of the different minerals. In that case no particular preference would be indicated for hornblende and biotite, and some particular method of behaviour in respect to the distribution of heat is the one that naturally suggests itself. We are not sufficiently acquainted with the behaviour of these minerals in regard to heat-conduction, heat-absorption, or heat-radiation to say what particular characteristic is the main cause of these appearances.

Variability and Amount of Micropegmatite of B Type in Different Granites.

Not the least interesting question in connection with the manifestations of the B type of micropegmatite is—Why should it be so variable in amount in different granites? And, in particular, why should it be altogether absent from some of them? We have already seen that it is related to some extent to the composition of the granites, being relatively less prevalent in the basic than the acid class of granites. We are now in a position, since we have discussed the *rationale* of its development, to state other conditions that must have had an important bearing on the relative amounts present in the different granites. Depending, as we have reason to believe, on the heat liberated by the crystallization of orthoclase and microcline, it will naturally tend to vary in amount with the amount of these minerals present. Generally in the acid granites where orthoclase is abundant, it will appear in largest amount. In the hornblendic granites orthoclase is less abundant, and there, as we have seen, micropegmatite is also less abundant. It is generally well developed where microcline is present in quantity, though exceptions no doubt occur. While these considerations may be stated as having an important bearing on the question at issue, it may also be stated with some confidence, that this explanation by itself does not cover the whole case. Some relation to position in the granite mass is undoubtedly indicated. And the indications, such as they are, which have been brought out by this research seem to be at variance with the views previously held in regard to the conditions favouring the development of micropegmatite. I think, however, that an important distinction has to be drawn between the B and C types of micropegmatite, and it will be evident from what has been already said, that the two types suggest different—very different—conditions for their development. For the B type we should expect, on the theory of its origin before enunciated, that conditions where heat conservancy were at a maximum would be the ideal conditions for its development, and this is precisely what such observations as have been made in this research unmistakeably point to. Sections from the margins or apophyses of granite masses have in a number of instances shown no micropegmatite, while others from the more central parts have shown it in abundance. I cite as examples Loch Moy granite, Inverness-shire, where sections from a central position in the boss showed its presence in considerable amount, while another section from the extreme periphery showed absolutely none. The same observation was made in the case of sections from a granite mass on Aitnoch Hill, Morayshire. In the Benrinnes mass it is much more plentiful in sections from the central mass, than in sections from the smaller outlying masses, though it cannot be said to be at all scarce in these. The same relations hold generally with regard to the Benachie mass. It is again practically absent from such pegmatite veins as have been examined, though a single micropegmatised plagioclase was seen in a section from a pegmatite vein in the Benrinnes area. Probably, however, this particular set of manifestations has not been sufficiently investigated. The conditions of the occurrence of the C type will be discussed along with the other details of that manifestation.

The entire absence of micropegmatite has, as stated, been noted only in a very few instances. The most notable example of its absence is Ben Laoghal granite, of which five sections in all have been examined, and in one instance only was a very ill-defined area of micropegmatite fringing a plagioclase felspar observed. I have no knowledge of the particular point or points in the boss from which the specimens were taken, and it is quite possible they may all have been derived from a peripheral position. In another case, from a small intrusion of a highly acid granite in the diorite of Aberdeenshire, no micropegmatite of this type was seen. The smallness of the mass might very well have been inimicable to its development in this instance. Of both these granites a very early development of quartz in very large amount is noted as a characteristic. This, from using up one of the minerals essential to the development of micropegmatite, might also be considered as a contributory cause of its absence. In other cases, where absence of micropegmatite is noted in the tabulated lists, the following possible determining causes have been noted in each case:—Granite vein in Netherly diorite—hyperacidity, small amount of orthoclase, and little or no plagioclase; Glengrant granite—small intrusion; Rora granite—much biotite, plagioclase, and quartz, little or no orthoclase; Corpach red granite—conditions unknown. It will be seen that all these embrace the two fundamental ideas of the absence of orthoclase and the facility for escape of heat. With regard to the group of hornblendic rocks, the absence of micropegmatite follows very closely the absence or scarcity of orthoclase. Where orthoclase is present in rocks of the diorite type, the presence of micropegmatite of this type may be expected. A notable example of this association is in the diorite of Auchmair, Cabrach. To sum up these observations—the presence of micropegmatite of the B type is associated with the presence of orthoclase and microcline, and conditions that make for the conservancy of heat. Its absence is associated with the absence or scarcity of these minerals and conditions that facilitate the escape of heat. Early crystallization of a large proportion of the quartz may be a contributory cause in some instances.

As regards the condition of heat conservancy which is essential to the development of the B type, it will be found to be diametrically opposed to the conditions of development of the C type of micropegmatite.

The C Type of Micropegmatite.

It has already been noted that the C type of micropegmatite hardly occurs in the typical granites. In one or two instances it is doubtfully present along with more or less micrograntic structure. Perhaps a few examples which occur in granites, and which have been described with the manifestations of the B type, should really be classified with the C type. These are instances where the crystallization of orthoclase had proceeded so far when, as it were, a deficiency of orthoclase substance supervened, and in consequence of this the remaining space was filled up with micropegmatite as a sort of compromise. Only in one or at most two granites have such structures been seen. They are typically seen in some specimens of Stratherric granite. The question that now presents itself, however, is—Why did the last portions of a magma to consolidate sometimes consolidate as micropegmatite of this type, sometimes as microgranite? And why in the majority of instances are both these structures absent? I think that, on the whole, we may extend the principle that we deduced as determining the formation of the A type of micropegmatite as against the formation of a true granite structure to these finer formations, as they are practically the same structure but only on a much finer scale. Rapid cooling is evidently a condition of the formation of both, and, as in the case of the macro-varieties of these structures, a sufficiency of water for full solution of the quartz may be considered an indispensable condition of the formation of microgranite; and an insufficiency of water, on the other hand, the condition of the formation of micropegmatite. This view will readily explain the occurrence of mixtures of the two, there being supposed to be sufficient water to keep in solution only a portion of the quartz in the case of a mixture, to dissolve it all in the case of its being totally micro-granite; and entire deficiency of water in the case of its being totally micropegmatite. The escape of water by volcanic action may be premised in the case of a number of the rocks examined. By reason of this the period of crystallization of the quartz would be brought forward so as to overlap the period of crystallization of the orthoclase. In all the cases observed quartz has still been the last mineral to crystallize, showing that a proportion of water still existed in the various magmas, up to the final stage of crystallization. Cases, however, occur, where orthoclase finishes up the micro-pegmatite groups, indicating that the quartz had all crystallized before the orthoclase finished crystallizing, in all probability from total failure of the necessary solvent. Volcanic action suggests further the reduction of pressure on the crystallizing magmas; but, if reduction of pressure were the sole cause of these appearances, one fails to see how mixtures of microgranite and micropegmatite could occur under the same pressure. That pressure may have some effect is not denied, but that it is infinitesimal in its action as compared with the water content of the last traces of unconsolidated magma cannot, I think, be doubted.

The absence of both microgranite and micropegmatite of the C type from the granite rocks generally, is of course due to the fact that most of these rock masses cooled slowly and in presence of sufficiency of water, at least in the final stages, to effect more or less perfect solution of the quartz up to the very close of its crystallization.

Metamorphism in Relation to the Development of Micropegmatite of the B Type.

One or two sections have come under observation during this research, which have a bearing on the relation of metamorphism to the development of micropegmatite of the B type. These are (1) a section of a garnet-bearing hyperite from the Battlehill, Huntly; (2) one of the sections of the Ben Cruachan felsite veins; and (3) a section of a foliated granite from near Portsoy.

(1) The sections of this rock, of which several have been examined, all show garnet, hypersthene, labradorite, biotite, magnetite, quartz, orthoclase, and microcline. The presence of the three last is attributed to infiltration from a neighbouring granitic intrusion. The orthoclase is frequently intergrown with the plagioclase, which consequently shows some corrosion. Only one of the sections examined, however, shows the presence of micropegmatite, and this, though in considerable amount, is strictly limited to the B type, and appears around the orthoclases as fringes in some of the plagioclases where they border orthoclase, and sometimes in the neighbourhood of the microclines. There cannot be much doubt that the appearance of the micropegmatite here is a metamorphic phenomenon, associated with the occurrence of quartz, orthoclase, and microcline. The garnet is of secondary origin. The occurrence of micropegmatite here supports the view that it is dependent for its development on an accession of heat, which in this instance has been derived from an external source, viz. a granite intrusion.

(2) In the marginal area of this vein, micropegmatite of the B type has been developed as fringes to some of the orthoclases of the encasing rock. At a distance of several microscopical fields from the margin of the vein, the small orthoclases and plagioclases of the encasing rock, which are embedded in the heart of the hornblende and biotite aggregates, were seen to be thoroughly micropegmatized. This is not a feature of the Ben Cruachan granite in any of the other slides examined, whether from the margin of these veins or at a distance from them. The micropegmatite, therefore, is ascribed to metamorphic action, or more precisely to the heat of the vein acting at some little distance from its source on the felspars of the bounding rock. Metamorphic action is also seen in the corrosion of some of the biotites where they come in contact with the vein. The corroded areas in the biotite have subsequently been filled in with irregular minute quartz grains, and present much the same appearance as occurs in the neighbourhood of biotite-corroded hornblendes.

(3) In a specimen from the foliated granite of Boggierow, near Portsoy, a rounded orthoclase was seen to show fringes of the very finest micropegmatite of the B variety. Here it had evidently been developed as an accompaniment of foliation, and leads us to infer that the heat generated by the movements that produced foliation had been sufficient at least locally to raise the temperature to the melting point of orthoclase or near it.

These three independent observations make for establishing the proposition that micropegmatite of the B type may owe its origin to an access of heat from an external source, and that that source of heat may be due to an intrusive mass or to the movements that produced foliation. In this connection it may be stated that such external source of heat is not excluded as a cause of micropegmatite of the B type in the case of some of the granites. It may have contributed to the results produced in a few instances; but from the all but universal distribution of this form of micropegmatite in granites it was evident that such could not be the cause in all cases, and an internal source of heat had to be sought for. These examples also show that heat from an external source may act at some distance from its source, and the same may be premised as being possible in the case of heat of internal origin. But it has to be borne in mind that with the former the degree of heat is not limited in amount and to a certain grade of temperature, as it must necessarily be with the latter

An Exceptional Form of Micropegmatite.

A section showing a peculiar form of micropegmatite was obtained from a white band in the gabbro near Inveramsay, Aberdeenshire, and may be noted as an example of micropegmatite which it has been found impossible to classify. The felspar in which it is developed is labradorite. Around the felspar it takes the form of fringes, and even the crystals in the heart of the ferro-magnesian mineral are found to show it. The second mineral which occurs in vermicular intergrowth with the labradorite is evidently not quartz but apparently another felspar, but this it is impossible to determine with any degree of certainty.

Possible Relation of Micropegmatite of the B Type to the Formation of later Acid Veins.

Looking at some of the "lacunar" and "extended fringing" forms of micropegmatite, such as have been observed in Kinsteary, Stratherric, and other granites, one could easily imagine the liquid that remained uncrystallized just before the development of micropegmatite as exuding into any fissures that might be formed in the cooling granite mass, and later, on itself cooling, giving rise to veins of a more acid character than the general mass of the granite. That such has been the origin of some of the smaller veins, such as those described as occurring in association with the Ben Cruachan granite mass, cannot, I think, be doubted. That some of the smaller veins in a granite mass have originated in this way has generally been held, but with regard to the possibility of such an origin it has not, so far as I am aware, been previously actually demonstrated as having a counterpart in the mass of the granite.

Relation of the Most Acid Granites to the Granophyres.

That the most acid granites and the granophyres are closely allied, or rather that the most acid granites grade into the granophyres, is shown by several points that have been brought out in this research. These may be brought together now. The acid granites, as has been demonstrated, show in marked abundance the A type of micropegmatite. This indicates a transition to the granophyre structure of the actual granophyres. Both rocks show a very highly acid composition. The acid granites, at least such of them as show the A type of micropegmatite, indicate, we have inferred, a deficiency of solvent water during their development, and a like inference may be extended to include the granophyres. Whether a more or less close relation to vulcanicity has been the actual cause of the reduction of the amount of the aqueous solvent may be left an open question; but the relatively superficial positions in the crust at which such rock masses have cooled adds an element of probability to the view. Another point which indicates the relative deficiency of water solvent is the fact, that, while the granites show biotite, a hydrated mineral, the granophyres, on the other hand, for most part show augite, which shows no water of constitution, as their ferro-magnesian mineral. Hence, more than one reason exists for believing that a deficiency of water in the original magma, or rather in its later stages of crystallization, was the real cause of the observed difference between granites and granophyres.

The Inertness of Quartz in Relation to the Development of Micropegmatite of B Type.

It certainly calls for remark that, while the crystallization of orthoclase and microcline is very evidently associated with the development of micropegmatite of the B type, quartz, which in its normal position of crystallization falls between these two minerals, should so seldom show any relation to its development. This must be due to some peculiarity of its crystallization. Either from its extreme slowness or the long interval between its melting-point and its crystallization-point, or some other recondite peculiarity, it does not liberate sufficient heat or liberates it so slowly that it is never at any time sufficient to affect the other minerals with which it is associated. On the other hand, its not being itself attacked by the heat liberated by the crystallization of the other minerals is easily accounted for, from the fact of its having the highest melting point of all the minerals in a granite, so that the heat liberated by their crystallization could never possibly reach its melting point unless where aided by the presence of the general solvent—water.

A Peculiarity of the Micropegmatite Areas in Rubislaw Granite.

In the grey granite of Rubislaw, Aberdeen, long colourless needles have been observed as colonizing the areas of micropegmatite of the B type and as being confined exclusively to these areas. As is well known numerous dark needles occur in many of the quartz grains of this granite. These, however, are quite different. They are much smaller, are brown or dark in colour, and are usually referred tô rutile. Those associated with the micropegmatite rather suggest sillimanite. If they are really sillimanite, I think it would afford some evidence that the felspars had undergone some change before the development of micropegmatite in them. In that case, it would follow that the micropegmatite was a later development and probably to be ascribed to an external source of heat.

Effect of External Heat on a Granite Mass.

From what has just been said, it will be inferred that the effect of heat from an external source may produce results which are not to be distinguished from those produced by the heat of internal crystallization. Much will depend, of course, on the intensity of the heat of such external source, and it may be useful to consider what would be the effect of a gradually increasing temperature on a mass of granite. It will be evident that on a gradual rise of temperature, the minerals of lowest melting point would be the first to show effects. These in their order of melting points would be hornblende, albite, oligoclase, biotite, microcline, orthoclase, muscovite, quartz. Of course, questions of mutual solubility and chemical reaction between the several minerals would come in at an early stage, and to some extent affect the result. Hornblende and biotite, if present, in consequence of a raising of their melting points by reason of high pressure, might be expected to behave exceptionally and in consequence be rather late in showing evidence of melting. Still, in a hyper-silicated granite, there cannot, I think, be much doubt but that the quartz grains would be the very last to disappear. If the temperature did not reach the melting point of quartz, they might be expected to remain as more or less rounded grains, which on the recooling of the boss would be found distributed indiscriminately through the other minerals. Something of this kind may have happened in a small boss of granite at Clatt, Aberdeenshire, associated with the diorite there, which shows many rounded quartz grains distributed indiscriminately through its plagioclases, orthoclases, and microclines.

General Scheme of Crystallization of a Granitic Magma.

The conclusions of this paper may be best summed up by now giving in detail the various stages that appear to be indicated in the crystallization of a granite; and considering, as indeed there is reason for believing, that the normal biotite granites have been derived by differentiation from a hornblendic magma, we may set out a general scheme of crystallization for all granites somewhat as follows :—

(1) At a temperature probably somewhat above (Löwinson-Lessing's Law) 1100° C., hornblende (melting-point 1085°, Doelter) begins to crystallize.

(2) In supersilicated hornblendic magmas, quartz, orthoclase, and an acid plagioclase, or any combination of them, may appear along with the last of the hornblende to crystallize, the appearance of these minerals in this connection being apparently due to their solubility in the originally liquid hornblende.

(3) Partial resorption of these minerals, and in particular of orthoclase, may occur, apparently, in consequence of the heat liberated by the crystallization of the hornblende.

(4) Crystallization of sphene, sometimes simultaneously with, sometimes previously to the hornblende, and in some cases even somewhat later, and at times around previously separated and partially resorbed quartz, orthoclase, and plagioclase nuclei; but evidence exists, at least in the case of quartz, that it may separate with the sphene, and for the same reason as it separates with the hornblende.

(5) Crystallization of biotite, with occasional resorption of hornblende—probably in consequence of, or at least aided by the heat liberated by the crystallization of the biotite, with the subsequent separation of more quartz; but, independently of this, quartz, orthoclase and plagioclase may also appear in connection with biotite for the same reason that they appear in connection with the hornblende, viz., from solution in the originally liquid biotite.

(6) Crystallization of plagioclase with occasional resorption of some of the biotite, in this case probably aided by the heat of crystallization of the plagioclase, with subsequent liberation of magnetite. This action of the biotite in consequence of its greater heat of crystallization is more marked in the case of orthoclase at a later stage.

(7) Crystallization in supersilicated magmas of part of the quartz, often as micropegmatite of the A type along with plagioclase, and later, in like manner, with orthoclase also.

(8) Crystallization of orthoclase, with solution in part of the plagioclases, apparently from heat of crystallization of the orthoclase with subsequent development of micropegmatite of B type in the areas of solution.

(9) Solution also in part of the earlier orthoclases during the crystallization of the later orthoclases, also with development of micropegmatite of B type in the areas attacked.

(10) Crystallization of remaining portion of quartz with little or no action on the previously crystallized minerals.

(11) Crystallization of microcline if present, with partial solution of plagioclases and orthoclases—the latter in limited degree—with subsequent development of micropegmatite of B type in the areas of solution.

(12) Crystallization of remaining liquid magma, if any,—with varying conditions, occasionally as micropegmatite of the C type, occasionally as microgranite.

The foregoing paper embodies such conclusions as may fairly be deduced from direct observation of the phenomena. They are not put forward as final results, but only as to a certain extent suggestive. Many of the points raised could manifestly only be settled by direct experiment; but such, from the nature of the case, it will readily be admitted, lies quite beyond the sphere of achievement of the private geologist.

In concluding this paper, I beg to acknowledge the kindly assistance of Dr Horne, who was good enough to send me specimens of the granophyres and other rocks of Skye, as well as specimens of the basic micropegmatitic intrusives of the Lothians for the purpose of comparison; of Mr James Fraser, C.E., who sent me specimens of Loch Roag granite, and also of Mr T. W. Wallace, Inverness, to whom I was indebted for specimens of the Bonar Bridge granite and other rocks.

Description of Plates.

Plate XXVII., Fig. 1. Quartz, orthoclase, and plagioclase in hornblende. Diorite, Auchmair, Cabrach, Banffshire. × 24. Polarized Light.

FIG. 1.

FIG. 2

FIG. 3.

FIG. 4.

FIG. 5.

FIG. 6.

FIG. 7.

FIG. 8.

Corroded'

FIG. 2. Sphene enclosing quartz with fluid inclusions, green fibrous hornblende, magnetite, and a small sphene. Syenite, Dalltullich, Nairnshire. × 115. Ordinary Light.

FIG. 3. Micropegmatite of A type. Ben Nevis biotite granite. × 23. Polarized Light.

FIG. 4. "Corroded" central plagioclase, showing micropegmatite of A type with fringe of micropegmatite of B type towards microcline. Loch Roag granite, Lewis. × 23. Polarized Light.

PLATE XXVIII., FIG. 5. Rounded and "corroded" plagioclases in orthoclase. Benrinnes granite, Banffshire. × 25. Polarized Light.

FIG. 6. Alternate micropegmatite (B type) in small plagioclases. Kinsteary granite, Nairnshire. × 25. Polarized Light.

FIG. 7. "Corrosion" border in plagioclases, where they face large orthoclase, Hildesay granite, Shetland. × 24. Polarized Light.

FIG. 8. Micropegmatite fringing edges of all plagioclases surrounding a narrow central orthoclase. A large mass of micropegmatite also radiates from a small biotite into adjoining orthoclase. Lairg granite, Sutherlandshire. × 24. Polarized Light.