The Dhoon (Isle of Man) granite: a study in contamination.

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[Read March 17, 1931; communicated by the General Secretary.]

THE Dhoon granite is contained in sheets 8 SW. and 8 SE. of the 6-inch Ordnance Survey Maps of the Isle of Man. It is a boss-like intrusion of irregular outcrop (fig. 1), enclosing an area about one and one-third miles long in an east-west direction, and half a mile wide in a north-south direction. It has been intruded into rocks which form part of that division of the Manx slates known as the Lonan Flags, and has metamorphosed these to a certain extent.

Berger,[1] Henslow,[2] and Cumming[3] all give brief descriptions of the granite, but it was not until Lamplugh[4] visited the island on behalf of the Geological Survey that any further progress was made. He mapped and described the outcrop of the granite accurately (loc. cit. pp. 142–144) and W. W. Watts described some micro-sections of the granite and its associated rocks (loc. cit., pp. 312–314). The granite was termed by him a porphyritic microgranite. Actually, however, the granite is a product of contamination, and in the following pages the evidence for this statement is set forth in detail.

Petrology of the Granite.

Examination of the intrusion has shown that two well-defined varieties of the granite (Types A and B) are present. Type B is restricted to a small area near Kionehenin, the boundaries of which cannot be located with any precision. It also occurs as inclusions of varying size in Type A.

[1] J. F. Berger, Mineralogical account of the Isle of Man. Trans. Geol. Soc. London, 1814, ser. 1, vol. 2, pp. 29–65.

[2] J. S. Henslow, Supplementary observations to Dr. Berger's Account of the Isle of Man. Ibid., 1821, ser. 1, vol. 5, pt. 2, pp. 483–505.

[3] J. G. Cumming, The Isle of Man. London, 1848.

[4] G. W. Lamplugh, The geology of the Isle of Man. Mem. Geol. Survey United Kingdom, 1903.

Type A Granite.—In hand-specimens this is a rather fine-textured medium grey rock, with small phenocrysts of white felspar and pale-blue opalescent quartz. A noticeable feature is the irregular distribution of the biotite flakes and their tendency to occur in small clots, giving the whole rock a patchy appearance. These are set in a finer groundmass of the same constituents. Inclusions of a dark

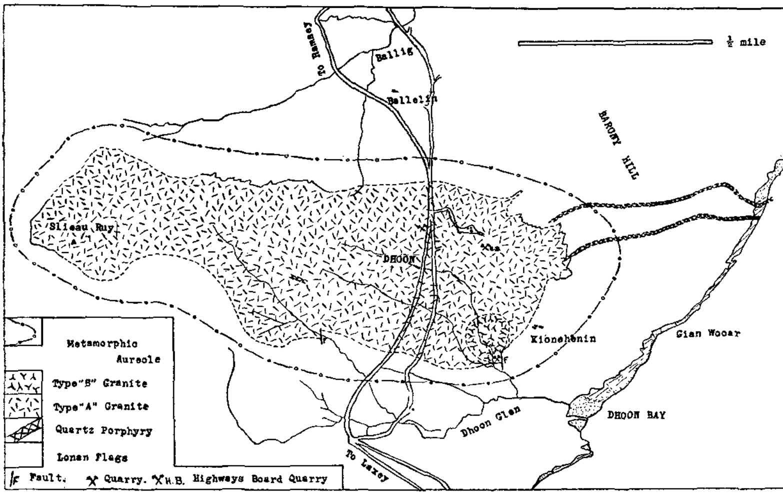


FIG. 1. Sketch-map of the granite mass, Dhoon, Isle of Man.
(Scale, 2 inches to 1 mile.)

rock are of very common occurrence. They are usually of small size and, indeed, are often but little larger than the biotite clots.

The felspar phenocrysts vary considerably in size; all have fairly good outlines, though sometimes rather marred by the encroachment of the groundmass. The largest measured was $6\frac{1}{4} \times 2$ mm., but sizes grouped around 2×1 mm. are the most frequent. Anything below this has been taken as belonging to the groundmass. This is a purely arbitrary arrangement because the felspars show seriate texture. These phenocrysts are all of plagioclase and have the composition Ab_{95} An_5. Even in the freshest specimens the felspars show a great deal of alteration with the production of zoisite and white mica, and sometimes a little chlorite and quartz. The alteration is apparently of pre-solidification date, because nearly every phenocryst is surrounded by a narrow rim of fresh felspar in optical continuity with and of the same composition as the felspar of the interior. Whatever the explanation of this alteration may be, there is no doubt that the plagioclase phenocrysts must originally have been more basic than they are now. This is borne out by the norm as calculated from the analysis. The process is thus essentially one of albitization. Lamellar twinning on the albite-law is a constant phenomenon, twinning on Carlsbad- and pericline-laws being less common. Zoning occurs but rarely, and always in specimens taken near the contact, where it has been favoured by rapid cooling. The zones, as far as could be determined, do not vary greatly in composition.

The quartz phenocrysts are present as rounded grains with sizes comparable to those of the felspar, but they do not show the same seriate arrangement. They form between 25 % and 40 % of the total phenocryst content in various specimens. All are more or less strained, but the intensity varies a good deal and a much-strained grain may lie next to an almost unstrained one. In places they are much cracked. Liquid and gas inclusions are of common occurrence, and sometimes mark out the rift and grain directions. Small rutile needles are frequent as inclusions. The phenocrysts of felspar and quartz together may make up anything from about 23 % to 30 % of the whole rock.

The biotite clots may occur close together or they may be more or less scattered. The biotite occurs as ragged flakes which show strong pleochroism from a pale straw-colour to a foxy-brown, sometimes inclined to be 'muddy'. Pleochroic haloes round small zircons are constantly present though not particularly abundant. There is also, quite frequently, a decided darkening of colour round inclusions of zoisite, suggesting that this too may be slightly radioactive. In some flakes the biotite may show a kind of schiller structure, due to bundles of minute needles of brown magnesian tourmaline lying along the cleavage planes. Sometimes this tourmaline occurs intergrown with the biotite as definite crystals and appears to be replacing it. Rutile is present in some instances, forming sagenite webs in varying stages of perfection.

The biotite clots may contain many flakes or, in rare cases, only one, but all show the same general features. In every case the biotite is associated with one or more of the following minerals: prisms of zoisite; ilmenite, generally with a border of granular sphene; more rarely sphene alone; occasionally grains of epidote and clinozoisite; and grains of garnet. These may be included in the biotite or lie at the margins of the flakes. A feature of the clots is the abundance of apatite needles in their immediate vicinity. There is good reason to believe, both from the constitution of the clots and from the evidence afforded by the inclusions which occur in the granite, that these clots are not normal but are derived from inclusions of another rock which have been more or less completely digested by the magma.

The groundmass of the rock is composed of quartz, felspar, and biotite. The texture is governed by the fact that the felspars have

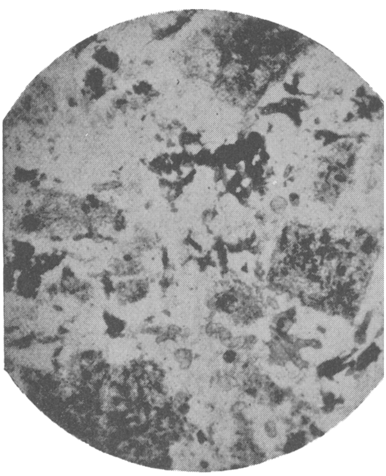


FIG. 2.

FIG. 3.

FIG. 2. Granite, Type A, showing the alteration of the felspar phenocrysts, and free from biotite clots. The specimen analysed. Ordinary light, ×24.

FIG. 3. Biotite clot. Another portion of the same slide as fig. 2. Biotite with ilmenite, sphene, some zoisite, and apatite needles in the vicinity. Ordinary light, ×40.

a strong tendency towards idiomorphic outline, whilst the quartz is granular. It is best described as microgranitic. The quartz grains are the most abundant constituent of the groundmass, and they show no signs of strain. They occur either partially or wholly included in the felspars or else fill up the interstices between them; or in places form a rough micrographic intergrowth. The next most abundant constituent is the plagioclase felspar (albite), the larger crystals of which are somewhat altered, but most of the smaller ones are quite fresh. Orthoclase, perthite, and microcline also occur, but only in small quantity. This was proved by etching a section with hydrofluoric acid and then testing for potash with sodium cobaltinitrite. Of these three potash-felspars, the first is the most abundant, the last is rare. The biotite flakes of the groundmass have the same colour and pleochroism as the larger ones that occur in the clots. How far they are original is unknown. It is, however, interesting to find that in a section particularly rich in clots the groundmass biotite was also more abundant than usual.

Accessory minerals include apatite, zircon, and rutile, already mentioned. There is also a fair amount of pyrite, a little magnetite, and in certain parts a little molybdenite. Calcite may also occur in the groundmass of the fresh granite, and in this sense is a primary constituent.

Type B Granite.—This is a black and white speckled rock, the black of the mica contrasting with the white of the felspar. The biotite aggregates are, on the whole, noticeably larger. Amongst the white portions of the rock grains of pale-blue opalescent quartz may be seen. The texture is granitic. Inclusions of a dark rock, similar to that found in Type A, are present in abundance, but are found to be of larger size and often have sharper outlines, as if this type has not been able to digest them as completely as Type A.

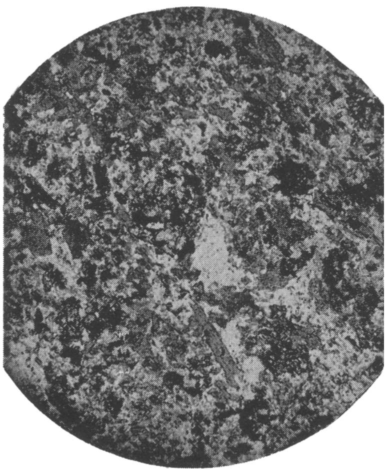
The minerals which occur are of the same nature as those already described under Type A. In this type, however, there is little or no groundmass present and the texture becomes normally granitic. The biotite clots are larger in this type, which gives it the appearance of containing more biotite than Type A. This is the case to a certain extent. It is interesting to note that Type A granite has good 'cleavage' whilst Type B has none.

Relationship of Type A to Type B.—The relationship of Type A to Type B is only shown in one place. This is the Highways Board Quarry where Type B forms a lenticular mass enclosed in Type A at the SE. corner of the quarry. At the time of visiting, the junctions were covered by quarry debris, and the information given below is due to Mr. Corteen, the quarry foreman.

The mass is completely surrounded by Type A, the top being about twelve feet below the quarry top. It passes gradually into Type A, there being no sharp junctions.

Three explanations are possible : (*a*) the whole granite mass represents a single intrusion in which certain portions (perhaps owing to richness in volatile constituents) were able to attain a normal granitic texture; (*b*) Type B represents portions which had crystallized at a greater depth, i.e. during the phenocryst stage of Type A, and have been carried up by Type A to their present position; (*c*) Type B is the remnant of a slightly earlier intrusion, which was overwhelmed, whilst still hot, by Type A. Taking all the facts into consideration, explanation (*c*) would seem the most probable.

Variations of the granite as a whole.—The granite (and this virtually means Type A, as Type B only forms a small proportion of the whole) varies in its biotite content from about 10–15 %. Locally, near inclusions or in patches where biotite clots are abundant, it may reach a much higher figure. The specific gravity varies from 2·68 to 2·76 in various specimens. It is found that there is a general tendency for the groundmass to become more siliceous in the higher portions of the intrusion. Further, at the actual contact with the Lonan Flags the biotite of the granite is converted to chlorite, often accompanied by secondary sphene, and secondary white mica is developed at the expense of the felspar.



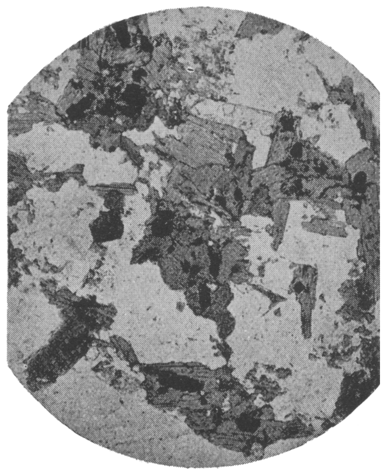


FIG. 4. FIG. 5.

FIG. 4. Centre of typical inclusion. Biotite, zoisite, ilmenite, sphene, paragonite, and albite are all present. Ordinary light, ×40.

FIG. 5. Biotite clot forming at the margin of an inclusion. Compare fig. 3. Ordinary light, ×40.

Chemical composition and classification of the granite.—A sample of the most normal-looking portion of Type A granite that could be found was chosen for analysis, and the result is given below, together with other analyses for comparison :

	I.	A.	B.	C.
SiO_2	71·20	72·33	71·70	72·55
Al_2O_3... ...	14·73	14·56	16·81	14·13
Fe_2O_3... ...	0·41	0·15		0·65
FeO	2·39	2·22	—	1·79
MgO	0·89	0·91	0·47	nil
CaO	3·06	2·55	2·42	3·53
Na_2O	3·50	3·40	9·00	4·47
K_2O	2·12	2·82		2·71
H_2O+ ...	0·80	0·30	—	0·37
H_2O- ...	0·20	—	—	—
CO_2	nil	nil	—	—
TiO_2	0·18	—	—	—
P_2O_5	0·12	—	—	trace
MnO	trace	—	—	—
S	0·30	—	—	—
Ni,Co,Zn ...	nil	—	—	—
	99·90	99·24	100·40	100·20

I. Dhoon Granite (Type A), Highways Board Quarry, Dhoon, Isle of Man. Analysts, W. H. and F. Herdsman.

A. Dacite, Kemp Mountain, North Carolina. Analyst, J. E. Pogue, 1909.

B. Aplodiorite, Inner Granite, Ben Nevis, Scotland. Analyst, B. Lightfoot, 1916.

C. Adamellite-porphyry, Okurra, Fukai Island, Japan. Analyst, E. Yokoyama, 1913.

The norm of analysis I, calculated in the usual way, is as follows :

Quartz	34·23	Corundum	1·43
Orthoclase	12·23	Pyrite	1·08
Albite	29·34	Magnetite	0·70
Anorthite	14·46	Ilmenite	0·46
Hypersthene $FeSiO_3$ ...	3·04	Apatite	0·34
Hypersthene $MgSiO_3$ ...	2·20	Water	0·80

The calculated mode is :

Quartz	36·42	Pyrite	1·08
Orthoclase	6·67	Magnetite	0·70
Plagioclase ($Ab_{67}An_{33}$) ...	43·80	Ilmenite	0·46
Biotite	10·64	Apatite	0·34

It will be seen that even allowing for the lime contained in the zoisite and sphene of the biotite clots, the plagioclase of the norm and the calculated mode will be at least as basic as $Ab_{75}\,An_{25}$. This gives some idea of the original composition of the plagioclase before it was albitized. The point is dealt with further under the heading of the contamination process.

The analysis shows that the rock falls into the granodiorite group except for the fact that ferric oxide is rather low, whilst silica is high. Although chemically and, to some extent, mineralogically a granodiorite or granodiorite-porphyry, yet the association of zoisite, ilmenite, sphene, &c., with the biotite shows that the rock is not of normal type. In the following pages, evidence is brought forward to show that this rock is a product of contamination.

The Inclusions of the Granite and the Contamination Process.

Inclusions are rather abundantly distributed throughout the granite. They can be divided into three classes:

I. Inclusions found only near the contact and derived from the surrounding Lonan Flags. These are not particularly abundant. They do not show any features of particular interest, being composed essentially of biotite and muscovite in a groundmass of quartz with a certain amount of felspar (probably albite). The biotite may be partly or wholly chloritized and may give the rock a pronounced foliation. Magnetite is associated with it. The inclusions are fine-textured, and there has been but little recrystallization. These inclusions have sharp boundaries against the granite and show no signs of assimilation.

II. Inclusions of sedimentary origin from some greater depth. One inclusion was found, about the size of a large biotite clot, which was composed of pink pleochroic andalusite and biotite. It had no definite boundaries with the granite, and obviously represents a small piece of slate which has been completely recrystallized.

III. Inclusions of igneous origin, derived from greater depths and responsible for the contamination of the granite. It has been mentioned before that inclusions of a dark rock are distributed throughout both types of granite. These are the ones that come under the present heading. They are better defined and appear to be more abundant in Type B granite than in Type A, but this would seem to be chiefly due to the fact that Type A was able to disintegrate and incorporate them more effectually than Type B. These inclusions are all of small size, ranging from several inches down to the size of the biotite clots already described in connexion with the granite.

Viewed macroscopically, the inclusions of the last class are black or dark brown in colour, and sometimes show sharp boundaries with the enclosing granite; in other cases this boundary is not so well defined.

Under the microscope, it is evident that they have been completely recrystallized. They now consist of an aggregate of biotite plates showing pleochroic haloes, zoisite prisms of small size, white mica as tiny flakes, and granular albite. Sphene and ilmenite (generally with a border of granular sphene) are nearly always present in some quantity, a pale pink isotropic garnet is sometimes present, and rarely there is a little epidote and clinozoisite. The relation of the white mica to the albite is interesting. Some inclusions are in a more advanced stage of dissolution and alteration than others. In these the albite seems to replace gradually the white mica, a phenomenon which can also be noticed towards the margins of the inclusions. This antipathetic relation shows that, in all probability, the white mica is paragonite.

Other inclusions, whilst still preserving their original outline to a limited extent, show a more advanced stage of dissolution. In these, the white mica has been almost entirely replaced by albite, and quartz begins to occur throughout, but more especially in certain coarser areas. These inclusions have often been partially disrupted by the granite and the smaller pieces have floated away for a short distance. In these detached portions the biotite and zoisite are noticeably larger in size.

This assemblage, consisting essentially of biotite, zoisite, paragonite and (or) albite, is a very striking one and appears to be unique in that it has not been described before. It is a hydrothermal assemblage, and its occurrence here must be due to the fact that the magma which enveloped these inclusions was rich (perhaps exceptionally rich) in volatile constituents, especially water. This is borne out by the fact that the metamorphism produced in the surrounding flags is of a hydrothermal nature and has led to an extensive development of muscovite and chlorite. Further, there are quartz and quartz-tourmaline veins trending roughly north-south which are connected with the granite.

The most interesting feature of the more altered inclusions occurs, however, at their margins. Streaming out from the inclusion into the surrounding granite, masses of material can be seen which are, to all intents and purposes, biotite clots such as those described when dealing with the granite. The biotite flakes are larger than those present in the body of the inclusion and the zoisite prisms have also grown bigger. The ilmenite has its border of granular sphene and separate grains of sphene may be present. Their resemblance to the biotite clots which occur throughout the whole granite is very pronounced. These masses represent the last remnants of the portions of the inclusions which have been completely replaced by the granite. The albite and quartz probably actually went into solution in the magma (being low in the reaction series); while the biotite and its accompanying minerals have been left, as the magma could not dissolve them but only convert them into minerals with which it would be as far as possible in equilibrium.

Thus we appear to have all stages from the recrystallized inclusion down to the biotite clots preserved to us. Is it too much to suppose that the clots which are found in the granite, remote from any definite inclusion, have in reality been derived from the complete dissolution and disintegration of other inclusions? There seems little doubt that their origin must be attributed to some such cause.

What, then, was the nature of the original material which gave rise to these inclusions and clots? In the first place, it was rich in ferromagnesian material and comparatively rich in ilmenite. In the second place, it was rich in lime, but poor in quartz. The surrounding Lonan Flags obviously will not fit the case and it seems doubtful if any sediment would. On turning to the igneous rocks we have very suggestive support from one of the greenstone dikes which occur so frequently throughout the Manx Slates.

This dike is cut by the quartz-porphyry dikes (see map, fig. 1) which run from the granite to the coast. These dikes are later than the granite but obviously connected with it. They are quite normal quartz-porphyries with phenocrysts of quartz, felspar, and, more rarely, micropegmatite set in a fine-grained groundmass. The quartz may or may not have the pale-blue colour characteristic of that in the granite. The felspar phenocrysts are of albite with subordinate orthoclase, microperthite, and microcline. The groundmass in which these are set is composed of quartz, albite, potash-felspar, and small flakes of muscovite. This groundmass has on the whole a granular texture, but sometimes its little orthoclase crystals are fringed with a delicate growth of micropegmatite. Biotite, small ill-developed garnets, and sphene may sometimes be present and are usually associated together, but they are not essential constituents.

Near the contact with this quartz-porphyry, the greenstone dike shows that it has undergone thermal metamorphism in addition to its earlier regional metamorphism. At about three feet from the contact the greenstone consists of large and smaller crystals of an actinolitic hornblende set in a matrix which is composed of small flakes of white mica, zoisite, and a little albite. Ilmenite and leucoxene are present, and in places biotite is just beginning to develop from the amphibole. A specimen taken half an inch from the contact shows the most striking changes. Here the actinolite has almost completely disappeared, its place being taken by biotite. The rock now consists of biotite, zoisite, granular sphene, and ilmenite with a certain amount of albite and quartz. This assemblage is essentially the same as that found in the inclusions, and it seems fairly safe to say that they must have arisen from a rock similar in composition to the greenstone dike.

It now remains to discover how the inclusions attained their present assemblage, and what effect this may have had on the granite magma. It is immediately obvious that potash must have been introduced from the magma, and from examination of the amount of zoisite present in the inclusions one would say that lime has been lost to the magma. There may also have been other changes. With a view to determining this, analyses of a greenstone identical with the one described above, of an inclusion, and of one of the quartz-porphyry dikes have been made. One of the granite has already been given and is reproduced here for ease of reference. These are as follows:

	I.	II.	III.	IV.
SiO_2	45·70	50·70	71·20	75·40
Al_2O_3... ...	16·92	23·40	14·73	13·05
Fe_2O_3... ...	0·90	1·77	0·41	0·51
FeO	8·44	5·02	2·39	0·70
MgO	9·41	2·35	0·89	0·49
CaO	10·42	3·80	3·06	0·72
Na_2O	1·81	4·45	3·50	3·92
K_2O	1·02	4·38	2·12	3·87
H_2O+ ...	3·00	2·40	0·80	1·00
H_2O- ...	0·30	0·10	0·20	0·20
CO_2	nil	nil	nil	nil
TiO_2	1·80	1·14	0·18	0·18
P_2O_5	trace	0·08	0·12	0·07
MnO	0·36	0·18	trace	nil
S	trace	0·29	0·30	trace
Ni,Co,Zn ...	nil	nil	nil	nil
Total	100·08	100·06	99·90	100·11

I. Greenstone dike.
II. Inclusion.
III. Granite.
IV. Quartz-porphyry dike.

Analysts, W. H. and F. Herdsman.

It must be remembered that the granite chosen for analysis was one of the least contaminated specimens that could be found. It would doubtless be easy to find others with higher content of FeO and MgO. The quartz-porphyry dike shows no signs of any contamination, and is probably somewhere about the composition of the original granite magma before contamination (excluding, of course, volatiles, &c.).

Dealing first with the greenstone dike and inclusions derived from it, we find that the inclusion loses ferrous oxide, magnesia, and lime, but gains a considerable amount of potash, soda, and alumina. On the other hand, the granite as compared with the uncontaminated quartz-porphyry dike loses potash and soda, but gains ferrous oxide, magnesia, and especially lime. Thus we have here that reciprocal reaction which is the very basis of contamination.

It is to be noted that the inclusions are in no sense intermediate in composition between the greenstone and the quartz-porphyry, or between the greenstone and the contaminated granite. No mixtures of these could produce the inclusions; in other words, the reactions that went on were selective in character and emphasized certain constituents. Further, the contaminated granite gains ferrous oxide, magnesia, and lime in two ways. It gains these oxides when attempting to incorporate the inclusions because the biotite clots with their zoisite, &c., are left as relics, and it also gains them by the reciprocal reaction mentioned above.

The Loch Ailsh intrusion, although a syenite, shows considerable similarity in its reactions to the Dhoon granite.[1] On p. 99 the authors state that 'The sediment absorbs potash to form biotite with the magnesia of the dolomite, and the igneous rock absorbs lime. . .'. Again, on p. 101 it is stated that 'Pyroxene is never present, though masses of zoisite and biotite may have a prismatic outline as if they were replacing pyroxene. . .'. At Arnage in Aberdeenshire[2] the norite gains alumina and potash, but loses lime and magnesia to the xenoliths. Shale xenoliths in the norite of the Bushveld Complex[3] lose alumina and gain magnesia and lime. In Mull[4] the xenoliths of the tholeiite dikes gain lime, ferrous iron, and magnesia. Other cases are known where similar reactions occur.

[1] Mem. Geol. Survey Scotland, Expl. Sheet 102, 1926.
[2] H. H. Read, Quart. Journ. Geol. Soc. London, 1923, vol. 79, pp. 479–484.
[3] A. L. Hall and A. L. du Toit, Trans. Geol. Soc. S. Africa, 1924, vol. 26 (for 1923), p. 85.
[4] H. H. Thomas, Quart. Journ. Geol. Soc. London, 1922, vol. 78, p. 253.

Summing up, we may say that in the present state of knowledge it is found that lime, ferrous oxide, and magnesia are associated on the one hand, and potash, soda, and alumina on the other. Further, it is apparent that there is some sort of reciprocal relation between these two sets of oxides. The exact nature of this relationship is a subject for future research.

The transference of material to and from the inclusions can be explained in several ways, and until we have more knowledge of other examples, the matter must be of a more or less speculative nature. It might be due to some sort of absorption by the inclusion. Again, it may be due to the existence of a reciprocal salt pair or series of such pairs, but it would be a matter of some difficulty to determine this. Finally, it may quite well be due to the preferential leaching out of certain constituents from the inclusions by the volatiles present in the magma, these being replaced by material that they carry with them. It must be remembered that the magma is a melt of curious physical constitution. It contains viscous silicates and highly mobile volatiles. Even if these volatiles form compounds with the silicates, those compounds will tend to move with the volatiles rather than with the other silicates. Soluble silicates, such as those of potash and soda, will almost certainly form part of the volatile portion of the magma. Thus this portion will contain plenty of material with which to effect change in the inclusions.

In the present instance there is evidence of a preferential absorption of volatile constituents by the inclusions. All the minerals of the inclusion either have water of constitution or require water for their formation. Again, the abundance of apatite in the immediate vicinity of the biotite clots and in the inclusions shows that the volatiles were concentrated in the neighbourhood. The abundance of apatite in the immediate vicinity of clots and inclusions has been noted by various writers, and Wandke[1] has drawn special attention to its significance.

Preferential absorption is perhaps enhanced by the fact that the volatiles and the otherwise viscous melt must have a continuous tendency to 'unmix'. This absorption is a physical process and is followed, probably immediately, by interchange of material with reciprocal reaction—that is to say, a chemical process superimposed on a previous physical one. Whether this will hold for all inclu-

[1] A. Wandke, Amer. Journ. Sci., 1922, ser. 5, vol. 4, p. 156.

sions in all magmas is a subject for future work. No great degree of superheat is required for the contamination process. Bowen [1] has shown that superheat is only needed to bring the inclusions up to the temperature of the magma. After that reactive precipitation plays the dominant rôle.

Under the conditions prevailing in the magma, biotite was the only ferromagnesian mineral which could form. The magma could and did react with inclusions in such a way as to produce biotite from the original ferromagnesian material. In like manner zoisite (owing to its large solid specific volume) would be more stable than its analogue anorthite. So the magma reacted with the inclusion to produce zoisite from the anorthite molecule. All this probably took place while the magma was still largely uncrystallized. As crystallization proceeded and the magma became more viscous, it became prominent as a disrupting agent. The inclusions were broken up and small pieces floated off or were strewn about. That there was movement in the magma is shown by the fact that the biotite flakes of the groundmass, and even a clot itself, can sometimes be seen winding round a phenocryst.

Another remarkable feature of the granite can be attributed to its contamination. We have seen that the inclusions must have given lime to the magma in some quantity. This resulted in the early crystallization of a plagioclase felspar fairly rich in lime. Allowing for a certain amount of lime in the zoisite, sphene, &c., of the biotite clots, its composition as deduced from the norm of the granite already given was somewhere about $Ab_{75}An_{25}$. It may be noted here that Grantham [2] in dealing with the Shap granite, says 'A high content of biotite, sphene, and calcic plagioclase would be expected as the result of assimilation of a basic rock'.

In the present instance, however, this was not the whole story. As crystallization proceeded, the concentration of the soda molecules in the remaining liquid gradually became greater until the felspars, apparently not reacting quickly enough to keep pace with this enrichment, were completely out of equilibrium. The result was that the soda more or less completely replaced the lime of the felspars, which was thrown out in the form of zoisite. Bowen (loc. cit., p. 267) states that 'minerals may be desilicated in the presence of alkalic molecules'. This, no doubt, helped in the formation of

[1] N. L. Bowen, The evolution of the igneous rocks. Princeton, 1928, Chapter X.

[2] D. R. Grantham, Proc. Geol. Assoc. London, 1928, vol. 39, p. 328.

zoisite from the anorthite molecule. Water also left its mark on the reaction in the formation of paragonite from some of the soda molecule. Finally, when equilibrium was properly adjusted, a narrow rim of fresh soda-felspar was deposited round the crystals. Thus the alteration of the larger felspars of the granite, as previously described, was indirectly dependent on contamination. A rather similar alteration of felspars has been described by Goodspeed.[1] It is of special interest to find that he regarded the alteration of his early plagioclase-felspars as being connected with the absorption of schist by the magma with which he was dealing.

We have, then, been led to the conclusion that the Dhoon granite is a contaminated rock resulting from an alkali-granite magma which has absorbed basic igneous material. The fact that there is no trace of any appreciable amount of other material forming the inclusions, renders it probable that the magma was intruded into an older basic intrusion occupying much the same position as the present granite.

As the greenstones intruded into the Manx slates had been sheared before the intrusion of the granite, it seems reasonable to suppose that this older basic intrusion would also be in a sheared condition. This would help in the conversion of the basic rock into biotite, zoisite, &c., as there is a striking similarity between the minerals formed under stress conditions and those formed in a 'wet' magma.

The contamination has produced a rock which is chemically a granodiorite, falling into a normal rang and subrang, showing once again the fallacy of classifying rocks according to their chemical composition alone. Mineralogically, zoisite and ilmenite with a granular sphene border are minerals not found normally in rocks of granitic type, and these give the clue which leads to the determination of the true nature of the rock.

Summary and Conclusions.

1. The Dhoon granite forms a boss-like mass extending for about $1\frac{1}{3}$ miles in an east-west direction and for about half a mile in a north-south direction. It is intruded into the Lonan Flags which form part of the Manx Slate Series.

2. Detailed examination shows that two main types of granite are present, one of which is slightly earlier in date than the other and only forms a very small portion of the present outcrop. The difference between the two types is mainly textural.

[1] G. E. Goodspeed, Journ. Geol. Chicago, 1927, vol. 35, p. 662; 1929, vol. 37, p. 158.

3. The main mass of the granite may be termed a biotite-granodiorite-porphyry, whilst the other type present is a biotite-granodiorite. Both types are abnormal, however, in that the biotite occurs in clots and in association with any or all of the following minerals: zoisite, ilmenite (usually with a border of granular sphene), sphene, and, more rarely, epidote or clinozoisite, and garnet.

4. It is shown that these clots represent the last remnants of a basic igneous rock which has been absorbed by the original granitic magma. Further, this basic rock had almost certainly been regionally metamorphosed before incorporation and probably occupied much the same position as the present granite boss. Inclusions of this rock, now altered to an aggregate of biotite, zoisite, ilmenite with sphene border, sphene, albite, and (or) paragonite, with rarer garnet and clinozoisite, are present in both types of granite, and all stages in the formation of the biotite clots from these inclusions can be studied.

The theoretical aspects of this contamination are discussed, and it is finally concluded that the original magma was of alkali-granite type, poor in ferromagnesian minerals and similar in composition to the quartz-porphyry dikes which are associated with the 'granite'. In addition, all the evidence points to an extensive interchange of oxides between the original magma and the basic inclusions. Further, it is shown that the peculiar albitization of the felspars in the 'granite' of both types is indirectly dependent on the contamination.

Acknowledgements.—The author wishes to express his best thanks to Dr. H. H. Thomas, who originally suggested the examination of the intrusion; to Prof. O. T. Jones and Dr. M. B. Hodge, under whose supervision the work was done; to Mr. G. Barrow for much useful advice and for the gift of thin sections; to Dr. C. E. Tilley for kindly reading the manuscript; to Mr. P. M. C. Kermode of the Manx Museum; and finally to Miss H. Jackson for much help in the preparation of the manuscript.