XI. *On Differences in Chemical Composition between the Central and Marginal Zones of Granite Veins, with further evidence of exchanges between such Veins and the Contact Rocks.* By WILLIAM MACKIE, M.A., M.D.

(Read 19th April 1900.)

Previous suggestions as to exchanges.

IN a former paper attention was directed to the possibility of exchanges between granite veins and the rocks in contact with them. Some chemical analyses of such veins and their contact rocks, though not specially directed to the point in question, seemed to suggest that in some cases lime and soda had been carried inwards from the contact rocks into the granite veins, while potash, and probably the iron oxides and magnesia, had been carried outwards from the veins into the contact rocks. The analyses which accompany the present paper were undertaken with the view of testing the suggestions then raised, and the specimens now analysed have been selected from particular zones in the two series of rocks, with the view of detecting what variations of composition, if any, exist between the rocks of these various zones. It was believed that if such exchanges had actually taken place, a series of analyses, embracing on the granite side one analysis of a specimen from a central and another from a marginal position in each case, and on the side of the contact rocks one from a proximal and another from a distal position, would give results that would conclusively show whether there were such co-relative differences as could be explained by the passage of substances from the one side to the other and *vice versâ*.

New series of analyses of specially-selected examples.

Granite veins in quartz schists. (*A*) Rothes and in diorites. (*B*) Portsoy.

Such analyses have been made in the case of five granite veins (*A*) rising through the quartz schists to the west of the Spey, and exposed in section along the Rothes Burn from Rothes westward, and also in the case of granite veins (*B*) intruded in the diorites, and gabbros exposed on the shore along the west side of the East Bay at Portsoy.

Original suggestions confirmed.

Corresponding analyses have been made of the contact rocks in each case. The results of these analyses confirm in a remarkable manner the suggestions of my former paper; but they afford, in addition

Evidence of internal differentiation in veins.

Correlation of differentiation with exchange.

Relation of composition of veins to that of contact rocks.

Some results due to temperature differences.

decided evidence of other and no less interesting differences which also appear to arise from the operation of the same or similar causes. I refer to the differences which, as shown by the analyses, obtain between the composition of the central and marginal zones of the granite veins, and which in the case of at least one substance may without exaggeration be fitly described as extreme. Such differences point to the fact of a remarkable degree of differentiation having taken place in the veins themselves, and in conjunction with the analyses of the contact rocks they show that with this internal differentiation must be correlated such exchanges as have taken place. Some little evidence has also been obtained in favour of the view that such granite veins owe their composition in part at least to the character of the rocks into which they have been intruded. This to some extent is a necessary corollary to the theory of exchange. There is also evidence to show that possible differences in the temperatures of the intruded and contact rocks have had something to do with certain of the results observed.

Arrangement of analyses.

For convenience of reference, the analyses are divided into two main series—the (*A*) series, or those of the Rothes Burn granite veins, with their associated contact rocks; and the (*B*) series, or those of the Portsoy shore, with their associated rocks.

The (*A*) series are tabulated in four groups—

Series (*A*).

1st. A group of five analyses from the central parts of each of the granite veins.

2nd. A group of five analyses from the margins of the corresponding veins.

3rd. A group of four analyses from proximal positions in the contact schists in the case of four out of the five of these veins.

4th. A group of four analyses from a distal position in the contact rocks in the case of the four corresponding veins.

Series (*B*).

A similar grouping of central and marginal analyses of the granite veins, and of proximal and distal in the case of the contact rocks, has been made as regards Series (*B*). The correlated analyses in the several groups are indicated by corresponding letters, *a b c d e*. The composition of the centre of a vein can thus be compared with its composition at the margin; while the composition of the enclosing rocks at a point in proximity to the granite vein can be compared with its composition at a distance from the vein, as well as with the composition at the margin or at centre of the correlated vein. This arrangement facilitates the striking of averages, on which, of course, rather than on the individual analyses, what conclusions fall to be drawn will more immediately depend.

Character of veins of Series (*A*). Two classes—1st, Biotite bearing.

Now as regards the granites of Series (*A*), two of these, *a* and *b*, are fine grained, very hard and flinty, breaking with a marked conchoidal fracture, more particularly at their margins. They show black mica in contra-distinction to veins *c*, *d*, *e*, which are of the pegmatite type so common among the metamorphic rocks, and show muscovite as their mica. *a* and *b* are probably small lenticular masses in all likelihood connected with the large local granite masses, which in many respects they closely resemble. Like these, they show rutile needles in their quartz grains. Some difference was observed between the specimens from their central and marginal parts, largely due, I think, to a difference of hardness and a slight excess of black mica at the centre. *c* is a very small vein only two feet across, and shows white felspar and abundant muscovite. It is coarsely crystalline throughout. No difference could be detected by the eye between its central and marginal specimens. *d* is a very large vein 20 feet or more across, with whitish felspars. It shows pure pegmatite structure of quartz and felspar along the margin, whence the sample for analysis was taken. Centrally there is abundant muscovite and numerous red garnets. The central specimen analysed was fine grained, and contained some small red garnets. *e* is a vein with large flesh-coloured felspars. It is about 8 feet in width, and cuts the foliation of the schists at an acute angle. It has affected the contact rocks more than any of the others. These for several feet back are now so much decomposed that a representative proximal specimen of the contact rocks could not be found at less than 4 feet from its margin. The central specimen in this case was from a fine grained slice which to the naked eye looked like a compact felsite. The lens, however, showed numerous red garnets in addition to the ordinary constituents of the rock. The marginal specimen showed muscovite and also some garnets. In the case of the last three veins some difficulty arose in consequence of their coarsely crystalline character in securing what might be considered fairly typical specimens. I think, however, that the specimens chosen were what in the circumstances would be considered fairly typical. It may be noted that these three

2nd, Muscovite bearing, or Pegmatites.

Difficulty of selecting typical specimens of pegmatites.

veins were not what would be understood by segregation or exfiltration veins, at least in the ordinary sense of these terms. Their margins were well defined, and in two cases at least they were seen to be separated from the surrounding rocks by open fissures.

Not segregation veins.

As regards the corresponding schist specimens, it is to be noted that none could be found in the case of vein *a.* In the case of the others they were obtained as far as possible from the same lithological stratum, the proximal as near to the vein as possible, the distal at the distance of several feet. For the reason that there was no continuous exposure of the rocks, these distances were not at all uniform. In the case of *e*, for reasons already stated, the proximal specimen was taken at 4 feet distant, the distal at 20 feet. A specimen from a position a few inches distant was analysed, but it was so decomposed that it was thought better to discount it altogether. No particular differences were to be observed between the proximal and distal specimens in each case on naked eye examination. The results of the analyses, however, suggesting the existence of such differences, led to their closer examination when in more than one instance the proximal specimen was found to be richer in felspathic substance than the distal.

Specimens of contact rocks at what distance selected.

Naked eye differences between proximal and distal.

The granite veins of Series (*B*) probably belong to the same intrusive series, but to a later phase. There is evidence that the contact rocks had cooled down and developed a jointed structure before the appearance of these dykes. They present in each case a marginal band of variable but no great width, showing very different characters from their central parts. These bands are markedly harder, sometimes of slightly different colour, and contain their minerals in different proportions. The veins, themselves, as they are traced along the shore, are seen to vary in width from a few inches up to several feet. They often expand abruptly, and such expansion has in more than one instance been observed to take place along a dominant cross-joint. Veins *a* and *c* are not very dissimilar, except in regard to the chilled margins, to veins *c*, *d*, *e* of Series (*A*.) They perhaps more closely resemble *e* of that series. Vein *b* of this series affords unmistakable evidence of rapid chilling. It shows along the margins porphyritic pink orthoclases and occasionally rounded blebs of quartz in a flinty and completely undifferentiated base. This structure extends through the whole vein where it is only about a foot in width, though there is some evidence even then that the porphyritic felspars are more numer-

Character of veins of Series (*B*).

ous at the centre than the margins. Where it widens out it assumes a structure, foliation, and general appearance not unlike some of the darker western gneisses. The contact rocks in this instance are basic igneous. In the case of *a* and *b* they are coarsely crystalline, and show augite labradorite and some iron ores, as their constituent minerals; in the case of *c* they are much finer grained, and show, in addition to a pyroxene and a lime felspar, (some decomposition) products. No difference could be made out by the naked eye between the proximal and distal specimens in each case.

Character of contact rocks of Series (*B*).

Analyses of granites. Veins of Series (*A*). General characters.

To take up the analyses of the granites of Series (*A*), it is interesting to note that none of these show a composition markedly different from what is known as the local granite type, as shown by the analyses of Benrinnes or Cairngorm granite, except that some of them are considerably richer in alkalies, and that their dominant alkali is in every case without exception soda, as against potash, as shown in the case of the granites mentioned.[1] The two biotite-bearing veins, *a* and *b*, show a considerably higher average percentage of peroxide of iron than do the pegmatite veins *c*, *d*, *e*. In these also magnesia, which is no doubt in part at least associated with the oxide, is also slightly higher than in the latter veins. The uncertainty however, attaching to the estimation of such small quantities of this base as are present in either, may raise a reasonable doubt as to whether the actual differences are fully represented by the figures. In every other respect they practically fall into line with the other veins in every respect.

Differences between central and marginal analyses of veins of Series (*A*).

Now as regards the differences brought out by the analyses between the centres and margins of the different veins, it will be seen that the marginal zones are considerably more basic than the central. To enumerate the differences in detail, there is on the average 1·22% less silica, 1·5% more alumina, ·33% less ferric oxide, ·85% less manganous oxide, ·31% less lime, but 1.88% more alkalies, at the margins

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[1] In this connection it is interesting to note that out of eighteen analyses of crystals of orthoclase, two specimens from granite veins rising through talcose slate, about a mile further east than Series *B*, were found by the late Prof. Heddle to contain the smallest relative proportion of potash and the largest of soda of the whole group. His results were—

K_2O 9·87°/o	Na_2O 3·34°/o
10·02	3·19

Though the analyses of pure minerals can in no sense be compared with the bulk analysis of these rocks, yet Prof. Heddle's results indicate a distinct predisposition (in their case) to what might fitly be called the soda diathesis.

than at the centres. While the differences in the intermediate bases are in some cases so slight that if taken by themselves—that is, without comparison with the results in the other series—they might possibly be considered accidental, the difference in the amount of alkalies cannot be held to be other than fundamental. Further, when it is observed that 85·7% of this increase is in potash, and only the remaining 14·3% in the soda, the difference becomes still more interesting. If the individual analyses be examined more closely, it will be seen that if those of vein *d* (which, by the way, is the most differentiated of the series) be discounted, the amount of soda is within the limits of estimational error, at centre and periphery absolutely identical. All the margins give an average of 4·915%; all the centres an average of 4·875% of soda; while the largest difference between a centre and its corresponding margin is ·11%.

Marked excess of potash at the margins.

Equality in the soda at centres and margins.

The inference from this is that there has been a movement of the potash from the centre to the periphery, while the soda has remained stationary throughout. Among the other differences only the proportions of manganous oxide call for a passing remark. Its relatively high percentage at the centre compared with what obtains at the margin is certainly peculiar in the case of rocks that usually show but the merest trace of this base. Whether its presence in relative abundance at the centre is to be ascribed to its being a residual product of the differentiation, or is due to infiltration from the contact rocks, which, as will be seen, are fairly rich in this base, might be left an open question. The practical absence of manganous oxide, however, from the other series of granite veins, as well as from the contact rocks, seems in favour of the latter view.

Movement of potash from centre to periphery of veins.

Peculiarity of manganous oxide—excess at centres.

Taking now the contact rocks, we find that the proximal and distal analyses present differences which, in some cases at least, are very evidently correlated with the differences observed in the analyses of the centres and margins of the granite veins. These rocks are considerably more basic at points in proximity to the granite veins than they are at points at a distance.

Differences between proximal and distal analyses of Contact rocks.

The proximal analyses show 4·12% less silica, 1·82% more alumina, ·55% more ferric oxide, ·05% more magnesia, ·19% less lime, ·04% more manganous oxide, and 1·66% more alkalies. These differences, be it observed, exist between the rocks at an

Some differences correlated with those of veins.

Marked excess of potash in the proximal.

A slight excess of soda in proximal, probably accidental.

average distance of 16 inches, and of 9 feet from the veins. While the minor differences of the intermediate bases may, as in the previous case, be ascribed to accident and purely observational error, it will however be found that they are, in some cases at least, in some way correlated with the differences observed in the case of the granite veins, and this view will be further corroborated when we find that Series (*B*), to be afterwards examined, in a number of instances show similar differences. There can, however, be no mistaking the meaning of the increase of the alkalies in the proximal analyses, and the connection between the increase of alkalies in this position and the observed excess of alkalies at the margin of the granite veins becomes emphasised when we find 82·5% of the increase is due to potash, and the remaining 17·5% to soda. While there are differences in the relative amounts of soda among the proximal and distal determinations—now the proximal, now the distal being in excess—as regards the potash, the proximal are uniformly markedly in excess of the distal. Over all there is only a small excess, ·28% of the proximal over the distal as regards soda. This may or may not be, but probably is, accidental.

Relative composition of veins and contact rocks.

Latter as a group relatively rich in soda and lime.

It is to be noted that the contact rocks are relatively richer, as a whole, than the corresponding granite veins in silica and the following bases—ferric oxide, lime, and magnesia; while they are poorer in alumina, manganous oxide, and alkalies. It is also interesting to note that the schists at a distance from granite intrusions, as shown in the four distal analyses now given, and in three other analyses from the same series of rocks, also from specimens taken at a distance from intrusion, and the analyses of which have already been communicated to this Society, show in five out of the seven a preponderance of soda over potash; the average of the seven being—potash, 1.94%; soda, 2·53%. The corresponding percentage of lime is found to be 2·09%. We must therefore conclude that the series of the contact rocks is one relatively rich in soda and in lime.

Analyses of veins of Series (*B*).

To pass now to Series (*B*), we find that among the granite analyses the central of vein *a* is exceptional among the granites of both series in being the only example showing a marked preponderance of potash over soda. This vein is also remarkable

An exceptional case.

Another vein of special character.

May show fusion in bulk of contact rocks.

for the extreme difference of composition between its central and marginal parts. Vein *b* is also exceptional in being rather a porphyry than a granite. In the proportion of its intermediate bases, more particularly as shown by its central analysis, it differs markedly from all the others. So much is this the case that some of its peculiarities might be ascribed to the actual fusion in bulk of part of the contact rocks. Taking the average of the central analyses of the series—and some of the other analyses would certainly yield a more favourable basis for comparison—I find that a mixture of four parts of a rock having the composition indicated, with one part of a rock having the composition of the average of the three distal analyses, would give a composition of—SiO_2, 70·03%; Al_2O, 14·72%; F_2O_3, 2·95%; MnO, ·09%; CaO, 3·31%; MgO, 1·07%; K_2O, 2·36%; and Na_2O, 4·33%; a result which would not be very dissimilar, particularly in the proportions of its intermediate bases, from the central composition of *b*. The differences are certainly not so marked as to warrant our entirely discarding this possible view of the origin of this dyke.

Two sets of granite veins compared as regards analyses.

Before proceeding to note the general differences between the central and marginal analyses of these rocks, it will be useful to compare the two sets of granite veins in relation to the results of their general analyses. From the silica percentages and analyses generally, Series (*A*) are seen to be more basic at the periphery than the centre. Series (*B*) more basic at the centre than periphery. The difference is, I think, to be ascribed to the different conditions under which the two series of veins cooled. Series (*A*) is richer in alkalies generally; but while Series (*A*) is richer at the periphery, Series (*B*) is richer at the centre. The former shows an average of 8·63% for total alkalies; the latter only 6·39%. Series (*A*) is relatively richer in potash than Series (*B*), the percentage of total alkalies being—

	For (*A*).	For (*B*).
Potash . .	37·5%	32·1%
Soda . . .	62·5	67·9

Series (*B*) is markedly richer in lime than Series (*A*), the averages being—(*A*), ·78%; (*B*), 2·07%, or nearly three times as much. The proportion of ferric oxide is—for (*A*), 1·8%; for (*B*), 1·43%. There is also to be noted a slight rise in the magnesia in the case of (*B*); ·34% as against ·18%.

To pass to the comparison of the central and marginal

Differences between central and marginal analyses of Series (*B*).

analyses of Series (*B*), the differences observed are not so marked as in the case of Series (*A*). The following differences, however, may be noted. There is a preponderance of 2·07% of silica in the marginal over the central averages of only ·12% ferric oxide, ·14% of lime, and ·03% magnesia; while there is a deficiency of 1·54% of potash, and ·54% of soda, giving a total of 2·08%, but on the opposite side of the balance to what obtained in the veins of Series (*A*). If, however, vein *a* be discounted, it will be found that the other two follow Series (*A*) in respect of shewing a general preponderance of soda over potash, and a higher percentage of potash at the margins than the centre; while they differ from these in showing a very much higher percentage of soda at the centre than the margin, as will be remembered, an absolute equality in respect of that base being observed in the case of four of the veins of that series. There is thus a balance of points of resemblance over points of difference between the two series of granites. These resemblances are masked in the general averages in the case of (*B*) by the preponderance of a single exceptional case.

Differences between proximal and distal analyses of contact rocks of Series (*B*).

Possible wave of arrestment of lime in proximal.

To pass to the contact rocks of the same series, we have in the silica and alumina percentages practical concordance between the proximal and distal analyses. There is ·54°/o less ferric oxide in the proximal than distal. This harmonizes with the slight peripheral increase in the granite veins. The excess of ·85°/o lime in the proximal over the distal seems anomalous considering the relatively high percentage of lime in the granite veins. It is possible that the excess may represent a wave of arrestment of the inflowing lime in the contact rocks at the margin of the veins. Indeed, a similar explanation might be given of the slight excess of soda in the case of the proximal rocks of Series (*A*). The proximal analyses also show an average of 2·32°/o more magnesia, ·13°/o more potash, and ·76°/o less soda than the distal; and there is a less total of alkalies at the proximal position by ·63°/o. In the totals, potash counts for 21·8°/o and soda 70·2°/o of the proximal; while potash counts for only 14·5°/o and soda for 85·3°/o of the distal. There is thus a relatively considerably larger proportion of potash in the proximal than the distal; while as regards the soda, there is over all a marked excess, both actual and relative, in the distal. The proximal increase of potash is comparable with the increase which was found to obtain in the proximal increase of the same base in the case of Series (*A*). Here

Deficiency of soda and excess of potash in proximal reverse in distal.

the results as regards the soda, which were set down as probably accidental in the case of that series, are found to be unequivocal in showing a proximal deficiency and a distal excess. The somewhat exceptional case of *a* in the basic rocks, which shows a higher proximal than distal, may or may not have some relation to the markedly exceptional case of the correlated granite vein.

Any method in results?

Passing from the consideration of the resemblances and differences observed among the several classes of rocks, we have now to inquire whether any system obtains among the points of resemblance or the points of difference now correlated. Before going on to do so it will be advantageous, in order to have a definite basis of comparison, to consider what was the possible composition of the original magma from which the several granite veins were derived.

Fixing on a standard granite for comparison.

With this view I propose taking either the analysis of Benrinnes or of Cairngorm granite, both of which have already been communicated to this Society. Perhaps the mean of the two, for they are not sensibly different, may be preferable to either. For the sake of comparison I give in parallel columns the composition of these two granites, I. and II.; the mean of the two, III.; the average of all the veins of Series (*A*), IV.; of all the veins of Series (*B*), V.; the mean of the two biotite-bearing veins *a* and *b* of Series (*A*), VI.; the average of the pegmatites *c*, *d*, *e* of Series (*A*), VII.; and the composition of the centre of vein *a* of Series (*B*), VIII, which might also be taken as the type of the undifferentiated magma of that or even of both series.

Granite of local bosses—composition as compared with veins.

It will be seen from this table that the granite of the two central bosses is more acid than any of the granite veins, and more particularly so than the pure pegmatites, which are the most basic of the whole series. It will also be seen that these differ from one another to the greatest extent in the relative proportion of their alkalies, the bosses having potash as their predominant alkali, while the pegmatites have soda as their prevailing alkali. The former, to enumerate the minor differences, are considerably richer in ferric oxide; they are poorer in lime, manganous oxide, and it may be magnesia. If we are to believe that the latter set of rocks have been derived from the former, it becomes necessary to consider the processes by which the changes observed have possibly been brought about. We have first of all these broadly associated facts. In the case of Series (*A*) we have a series of veins rich in soda as compared with potash;

Process by which one might be changed into other.

Broadly associated facts as to composition of veins and contact rocks.

relatively rich in lime, manganous oxide, and to a less extent magnesia, existing in association with rocks which, as analyses have shown, have also an excess of soda over potash, and are at the same time comparatively rich in lime, manganous oxide, and magnesia. In the case of (*B*) we have a set of granite veins which show a greater relative excess of soda over potash, a much higher proportion of lime, and at the same time though only a slight deficiency of ferric oxide of magnesia over what obtains in the former set, associated with rocks which also show a relatively greater excess of soda over potash, and a very large excess of lime, iron oxide, and magnesia over the contact rocks of the former series. It is impossible, therefore, to overlook the possibility that the associated phenomena may stand together somehow in the relation of cause and effect. If this surmise be correct, what have been the steps of the process by which the original magma—a magma, we shall say, of similar composition to the granites of Benrinnes or Cairngorm—has been changed into granites with the composition shown in column VII. of the table already given?

Possible relation of cause and effect.

How original magma changed to composition of pegmatites.

In the case of the granites of Series (*A*), it has been demonstrated beyond chance of mistake that there has been a movement of the potash from the centre of the veins to the periphery, as shown by the average of the marginal analyses showing 1·61°/₀ more potash than the averages of the centres. This has probably taken place by the process, however it may have arisen, which is usually known as differentiation. But the process has gone further, and we find unmistakable evidence that the potash has also passed out into the contact rocks by the fact that the proximal analyses of these rocks show 1·32°/₀ more potash than the distal.[1] In like manner we have evidence, more particularly in the case of Series (*B*), though perhaps somewhat less cogent, that there has been a counter current of soda from the bounding rocks into the granite veins by the distal rocks showing ·76°/₀ more soda than the proximal; in association with veins relatively richer in soda generally than the veins of Series (*A*). In the case of Series (*A*), the evidence from the analyses for an inward movement of the soda is somewhat equivocal. It is in fact possible, considering the stage of

Movement of potash to periphery of veins and out into Contact rocks.

Counter current of soda.

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[1] The increase of potash in the proximal rocks of (*A*), the increase of lime and the decrease of iron oxide in the corresponding rocks of (*B*) may also, though less probably be ascribed to temperature effects of the intrusives in facilitating movements of these bases in the contact rocks themselves without actual exchange between the two sets of rocks.

differentiation which these rocks have reached, that it may have been replaced by a slight outward movement in this case. Given, however, the possibility of an outward flow of potash and an inward flow of soda, it becomes simplicity itself to explain the presence of excess of potash in the original magma, and the presence of excess of soda in the derivative pegmatites and other apophyses. The other minor differences observed are explained on the same lines. In both series of veins there is an excess of lime over what appears in the undifferentiated rock, and the excess in each case is roughly proportional to the excess of the same base in the contact rocks. This may be typified thus—

Explains excess of potash in magma, and of soda in veins.

CaO in pegmatites of Series (*A*) .	·86%,	in Series (*B*)	2·07%.
CaO in the original magma . .	·52	,, ,,	·52
Excess in favour of pegmatites .	·34	,, ,,	1·55
Lime in contact rocks in case of (*A*)	2·07	,, ,,	9·01

or roughly six times the difference in each case. We therefore conclude that there has been an inward movement of the lime in each case. Again, the ferric oxide is less in the pegmatites than in the original magma, the proportion being—pegmatites 1·32%, magma, 1·83%, and this is correlated with an excess of ·55% of the same base in the proximal as compared with the distal analyses of the contact rocks. We therefore infer an outward movement of the ferric oxide. In the case of Series (*B*) two out of three marginal analyses would seem to indicate a very slight inward flow of iron oxide; but it must have been very slight, as we have only a very slightly higher proportion than the pegmatite, or 1·43% as against 1·32%, and this, it should be remembered, with a very much higher percentage of iron compounds in the contact rocks. In this connection it may be noted that a slight inflow of ferric compounds may also be indicated in the case of the biotite containing rocks of Series *A*, as they show a higher percentage than the original magma, 2·51% as against 1·83%. These differences appear to indicate differences in the direction of the movement of the same base at different stages of the differentiations, and presumably at different temperatures, both of the magma and the contact rocks. The presence of manganous oxide in the pegmatite, particularly at the centre, can only result from the inflow of that base from the contact rocks, as the original magma

Inward movement of lime and outward of ferric oxide.

Possible change of direction of ferric oxide in Series (*B*) and biotite-bearing veins of (*A*) due to differences of temperature.

Inward movement of manganous oxide.

as represented by the granite bosses is particularly free of it. As regards the magnesia, from its small amount in any case, there may be some reason for withholding a deliberate opinion. There is some evidence, however, in both series of veins of a slight inward flow.

Small amount of magnesia gives room for doubt.

As a corollary to these exchanges there comes as a necessary sequence, mineral changes in the resulting rocks. With the flowing away of the excess of the iron oxide goes the possibility of the formation of black mica, and in its place, and probably also as result of increased facility of hydration, the formation of muscovite. With the inflow of lime and manganous oxide, on the other hand, comes the possibility of the formation of garnets. Curiously enough, however, no garnets have been observed in the veins of Series (*B*), which are the richer of the two in lime. The probable scarcity or absence of the manganese base may account for the fact. From the relatively low proportion of alkalies in the marginal zones of the veins of this series one cannot help thinking that the lime has helped the soda to replace the potash in the felspars in this case.

Necessary sequence of mineral changes.

Absence of black mica, presence of muscovite and garnets in pegmatites.

Lime possibly replacing potash in felspars of Series (*B*).

On what, then, might fitly be called the theory of differentiation with selective exchange the whole phenomena of these dykes and their contact rocks may be easily explained. Certainly all the facts revealed by the analyses fall into line on this assumption. Even the anomalous case of vein *a* of Series (*B*) is explained on the supposition that we have here an example of the original magma, probably itself to some extent differentiated by the passage of an excess of potash to the periphery, rapidly injected along the centre of the vein between walls which had already been cooled and altered in composition by contact with and exchanges between them and the contact rocks.

Theory of internal differentiation and selective exchange.

Explains all facts revealed by analyses.

As regards the precise reason for such differentiation and exchange I do not at present presume to give or to hold a definite opinion. It may be said, however, that such differentiation and exchange appear to be due in some way to differences in the crystallising or fusion points of the several molecular groups that enter into the composition of the correlated rocks. Crystallising and fusion points, even for the same substance, may be very different things, and in some such way,

Cause of differentiation and exchanges.

May be related to crystallising or fusing points of the different minerals.

I think, it is possible that differences in the direction of movement of the same base, such as would seem to be indicated by some of the results, may have taken place at different phases of the evolution.

SERIES *A*.—GRANITE VEINS (MARGINS).

Veins	Silica SiO_2	Alumina Al_2O_3	Ferric Oxide Fe_2O_3	Manganous Oxide MnO	Lime CaO	Magnesia MgO	Potash K_2O	Soda Na_2O	Loss on Ignition H_2O, etc.	TOTALS
(*a*) . .	74·30	13·44	2·72	Trace	·89	·27	3·99	4·14	·49	100·24
(*b*) . .	74·96	12·27	1·96	1·02	·20	·20	3·60	5·51	·35	100·09
(*c*) . .	72·47	14·72	·93	Trace	1·10	·13	5·04	5·02	·72	100·13
(*d*) . .	72·81	14·36	·28	Absent	·36	·17	3·66	7·95	·31	99·90
(*e*) . .	73·00	14·29	2·27	·58	·52	·15	3·95	4·99	·43	100·18
Averages	73·51	13·82	1·63	·40	·62	·18	4·05	5·52	·46	...

SERIES *A*.—GRANITE VEINS (CENTRES).

(*a*) . .	76·82	10·58	3·14	1·28	·78	·18	2·71	4·05	·37	99·91
(*b*) . .	73·70	12·45	2·20	1·01	·70	·16	3·34	5·62	·57	99·75
(*c*) . .	74·03	11·63	2·07	1·62	1·21	·24	3·34	4·93	·84	99·91
(*d*) . .	74·88	13·50	1·13	1·59	·85	·16	·99	6·76	·34	100·20
(*e*) . .	74·22	15·18	1·25	·75	1·11	·18	1·83	4·90	·66	100·08
Averages	74·73	12·67	1·96	1·25	·93	·18	2·44	5·25	·56	...

SERIES *A*.—CONTACT ROCKS (QUARTZ SCHISTS).

Proximal Specimens.

In Relation to Vein	Distance from Vein Margin	SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	Loss on Ignition	TOTALS
(*a*)				No S	peci	mens	obta	ined.			
(*b*) . .	1 ft.	86·64	7·33	1·98	·34	·37	·16	1·69	1·12	·49	100·12
(*c*) . .	1 in.	75·25	10·01	5·01	·46	1·38	·65	2·78	3·61	·77	100·11
(*d*) . .	3 in.	74·01	11·86	5·19	·53	1·49	·54	2·32	3·13	1·02	100·09
(*e*) . .	4 ft.	72·10	13·76	4·02	·40	1·82	·57	4·06	1·93	1·54	100·20
Averages	16 in.	77·	10·74	4·05	·43	1·27	·48	2·71	2·45	·95	...

Distal Specimens.

(*a*) . .				No	Spe	cime	ns.				
(*b*) . .	2 ft.	81·11	9·38	3·98	·26	1·09	·86	·96	1·86	·59	100·09
(*c*) . .	2 ft.	84·67	7·86	2·20	·28	2·29	·05	·25	1·99	·48	100·07
(*d*) . .	4 ft.	82·18	6·61	3·67	·64	1·69	·43	1·66	2·34	·90	100·12
(*e*) . .	20 ft.	76·50	11·83	4·14	lost	·76	·36	2·70	2·48	1·11	99·88
Averages	9 ft.	81·12	8·92	3·50	·39	1·46	·43	1·39	2·17	·77	...

SERIES *B.*—GRANITE VEINS (MARGINS).

Veins	SiO_2	Al_2O_3	Fe_3O_3	MnO	CaO	MgO	K_2O	Na_2O	Loss on Ignition	TOTALS
(*a*) . .	76·34	13·58	1·79	Trace	2·11	·42	·78	4·06	1·03	100·11
(*b*) . .	78·71	12.45	1·23	„	1·78	·47	1·37	3·24	·80	100·05
(*c*) . .	72·88	14·31	1·46	„	2·52	·17	1·68	4·91	H_2O 1·21 CO_2 ·91	100·05
Averages	75·98	13·45	1·49	...	2·14	·35	1.28	4·07	1·32	...

SERIES *B.*—GRANITE VEINS (CENTRES).

(*a*) . .	74·14	14·88	·34	None	·38	·15	6·34	3·27	·47	99·97
(*b*) . .	72·85	13·50	3·03	·33	3·20	·71	1·22	4·70	·70	100·24
(*c*) . .	74·74	14·22	·73	None	2·42	·09	·89	5·86	H_2O ·67 CO_2 ·53	100·15
Averages	73·91	14·20	1·37	·11	2·	·32	2·82	4·61	·79	...

SERIES *B.*—CONTACT ROCKS (BASIC IGNEOUS).

Proximal Specimens.

		SiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	Loss on Ignition.	TOTALS
(*a*) . .	1 in.	53·54	18·81	8·56	...	10·30	4·54	·93	3·13	1·25	101·06
(*b*) . .	1 in.	55·46	15·28	8·83	...	9·03	6·93	·76	3·01	1·53	100·83
(*c*) . .	1 in.	55·11	15·97	8·83	...	8·93	7·78	·36	1·18	2·05	100·21
Averages	1 in.	54·70	16·69	8·74	...	9·43	6.42	·68	2·44	1·61	...

Distal Specimens.

(*a*) . .	4 ft.	51·02	18·84	9·68	...	12·12	4·79	·44	2·68	·77	100·34
(*b*) . .	4 ft.	53·92	15·05	9·10	...	8·48	4·55	·78	3·98	4·87	100·73
(*c*) . .	6 ft.	58·62	16·56	9·07	...	5·13	2·94	·42	2·94	4·53	100·21
Averages	...	54·52	16·82	9·28	...	8·58	4·09	·55	3·20	3·39	...

COMPARATIVE COMPOSITION OF DIFFERENT GRANITES.

	I Benrinnes Granite	II Cairngorm	III Mean of I and II	IV Average of Series *A*	V Average of Series *B*	VI 2 Biotite Granites of Series *A*	VII 3 Pegmatites of Series *A*	VIII Vein (*a*) of Series *B*
SiO_2	74·75	76·01	75·38	74·12	74·95	74·95	73·57	74·14
Al_2O_3	14·08	13·47	13·78	13·25	13·82	12·19	13·95	14·88
Fe_2O_3	2·12	1·54	1·83	1·80	1·43	2·51	1·32	·34
MnO	Trace	Trace	Trace	·82	·06	·83	·76	None
CaO	·49	·54	·52	·78	2·07	·65	·86	·38
MgO	·04	·06	·05	·18	·34	·20	·17	·15
K_2O	5·39	5·57	5·48	3·24	2·05	3·41	3·13	6·34
Na_2O	3·09	2·32	2·71	5·38	4·34	4·83	5·76	3·27
Ignition	·34	·56	·45	·51	1·05	·44	·55	·47

To facilitate comparison, the total iron oxides have uniformly been reported as ferric oxide. Some of the specimens of the contact rocks of Series (*B*) showed small proportions of TiO_2, but no separate estimations were made. These would fall to be included partly with the silica but mostly with the alumina. Phosphoric acid and sulphur, the latter in combination as pyrites, were also observed, but were not estimated. Phosphoric acid falls to the total of the alumina, and the sulphur would be partly covered by the oxygen of the ferric oxide. The fact that most of the analyses of the contact rocks of Series (*B*) sum up to nearer 101 than 100 may be taken as indicating that a large proportion of their iron compounds exist in the ferrous state. The TiO_2 sulphur and phosphoric acid were not considered sufficiently important from the point of view of the purpose of these analyses, and consequently the analyses were not complicated by their separate determination.

As regards the diapedisis of TiO_2, I have elsewhere demonstrated the possibility of its occurrence, the microscope showing the presence of rutile needles in the quartz grains of schist rocks in contact with granite veins and other igneous masses.