THE TOURMALINE-BEARING ROCKS OF THE HEEMSKIRK DISTRICT.

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The Heemskirk district was visited some weeks ago by one of the authors in the course of his official duties as Assistant Government Geologist. Most of the field observations then made have already been published in the report on the district recently issued by the Mines Department*, but the necessity of writing these reports as soon as possible after the examination of the district in question is completed precludes the possibility of a minute examination into the microscopical character of the rocks prior to publication. In the case of the Heemskirk district, not only are the field observations of more than ordinary interest, but the additional evidence afforded by micro-examination of the rocks is important. The authors, therefore, think that a short description of the rocks, both as regards their microscopical characters and their field relations, may not be out of place among the proceedings of this Society. It may also be mentioned that, since the publication of the Mines Department report, other portions of the district have been examined, so that some of the field observations here recorded are published for the first time.

Mt. Heemskirk is situated on the West Coast of Tasmania, about 24 miles north of the entrance to Macquarie Harbour. The district may be regarded as extending along the coast from Trial Harbour on the south to Granville Harbour on the north. The major axis of the mountain range runs approximately parallel to, and about 4 miles distant from, the coast. Mt. Agnew is the most southerly and the highest peak of the range, and rises about 2800 feet above sea-level. The mountain range is composed almost entirely of granite, which extends along the coast from a little north of Trial Harbour to beyond Granville. To the south and east of the granite the Silurian slates and sandstones outcrop, and these have suffered metamorphism near their contact with the granite.

* Report on the tin ore deposits of Mt. Heemskirk, by G. A. Waller, Assistant Government Geologist.

The Normal Granite.

The rock which we have termed the normal granite consists of a medium to coarse-grained biotite granite. It is much more widely distributed than the other types, and appears to be of more uniform composition. The rock shows, on microscopic examination, the following minerals:—Orthoclase, plagioclase felspar, biotite, quartz, tourmaline, iron pyrites, and apatite. The felspars have suffered much decomposition; the clouded appearance of the plagioclase felspar makes the determination of its character very difficult, but the low angle of extinction points strongly to its being oligoclase. It has preceded the orthoclase in the order of crystallisation. The biotite is very pleochroic, and contains on the whole very few inclusions; it appears to have undergone very slight alteration, but it is occasionally somewhat bleached, and a small amount of resorption with separation out of opaque material has taken place. Apatite in small grains is rare, and small masses of iron pyrites, destitute of crystal boundaries, are present. The main interest of the slides centres round the remaining minerals, quartz and tourmaline. The tourmaline occurs as short slender opaque rods, traversing the quartz grains in all directions. The rods, as a rule, are quite straight, but in some few instances they are curved; a radiant structure is very characteristic, the centre of radiation being sometimes a minute speck of opaque matter; in other cases the rods appear to radiate from the line of separation of two quartz grains, and the rods then show a tendency to lie parallel to this line of separation; no case was observed of a rod crossing the line of separation and penetrating both of two adjacent quartz grains.

The distribution of the rods in the quartz is very capricious; they crowd some grains and are comparatively rare in others, while sometimes the same grain may be rich in them in one part while the remainder of the grain is absolutely destitute of them. In one marked case a quartz grain is crowded with needles, and carries a moderate amount of minute opaque specks, while the remainder of the grain, though in optical continuity, is devoid of rods, and almost devoid of opaque specks. The phenomenon would appear to point to the presence here of quartz of two generations, the younger quartz having been deposited from a solution free from tourmaline, and having crystallised round an eroded grain of the older quartz in optical continuity with it. The presence of veins containing iron pyrites in the vicinity seems to support the hypothesis that this normal granite has undergone a small amount of metasomatic change.

Tourmaline Granites and Aplites.

These rocks occur in considerable quantities in many parts of the district, especially in the vicinity of known tin-bearing deposits. Tourmaline granites occur in the form of dykes and masses in the normal granite, and in the latter condition often extend over areas of some hundreds of acres. The tourmaline aplites, or fine-grained tourmaline granites, occur as irregular masses and nodules in the tourmaline granites, and also as dykes, both in the tourmaline granites and in the normal granites. Dykes, nodules, and masses of non-tourmaline-bearing aplite are also found in the normal granites, and dykes of the same rock traverse the tourmaline granite.

The tourmaline granites exhibit a large amount of variation, both in the proportions of the several minerals contained and also in the size of the constituent grains. We have only two somewhat imperfect slides of these rocks at our disposal, so that our description must be principally confined to macroscopical characters. The minerals which may be seen with the naked eye comprise the following:—Felspar, quartz, tourmaline, muscovite, and a dull green mica (probably biotite which has been partly altered to chlorite).

The most striking characteristic of the rock is in connection with the distribution of the tourmaline. This occurs in patches or bundles of radiating needles or prisms, from 1 up to 3 inches in diameter, usually associated with quartz. As the granite becomes finer grained, and approaches to the aplites in structure, the tourmaline loses its radiating character, and, together with quartz and a little felspar, forms more or less well-defined balls or nodules (quartz tourmaline nodules), which occur sometimes distributed at regular intervals through the granites, and sometimes collected together in masses. The groundmass of the rock consists of a medium to fine-grained crystalline granular mixture of quartz, felspar, and two micas. Small miarolitic cavities may be often observed, into which the crystal faces of quartz and felspar protrude. Under the microscope the felspar is seen to consist both of orthoclase and plagioclase, both much decomposed. The quartz differs from that of the normal granite, in that it contains no microscopic rods of tourmaline, the whole of the latter mineral appearing to be concentrated in the quartz tourmaline nodules.

With the exception of a little muscovite, there is no mica present in our sections. It may be said that the mica is generally present in much smaller quantities than in the normal granites, and in some cases it appears to be entirely absent.

From the above description it will be seen that the tourmaline granites differ from the normal granites in the following particulars:—

(1.) The greater amount of variation exhibited by the tourmaline granites, both in the mineralogical composition and in the size of the constituent grains.

(2.) The frequent presence of miarolitic cavities.

(3.) The presence of macroscopic bundles of radiating tourmaline or of quartz tourmaline nodules.

(4.) The absence of microscopic rods of tourmaline in the quartz.

(5.) The presence of small quantities of muscovite, which appears to be absent from the normal type.

(6.) The lesser abundance of biotite.

The tourmaline aplites, as has already been stated, occur in irregular masses in tourmaline granites, and as dykes in both the tourmaline granites and the normal granites. In neither case is there any sign of parting at the contact between the aplite and the granite. In the case of the dykes the walls are well defined, but there is no distinct plane of division, the one rock appearing to "grow into" the other. This phenomenon is ascribed by Rosenbusch* to the fact that the aplite was introduced into the fissures while the granite was still in a highly heated condition. In the case of the masses the contact is even less sharp, and it is sometimes impossible to say within two or three inches where the aplite begins and the granite ends. Occasionally the masses of aplite throw out irregular apophyses into the surrounding granite. The whole appearance of the masses gives the impression that they were formed while both magmas were still liquid, and one may ascribe the irregular shape of some of them to movements in the still molten magma. The aplites are usually much richer in tourmaline than the tourmaline granites. The mineral is, however, confined to the quartz tourmaline nodules, which are often very abundant, and generally are almost perfect spheres. The quartz tourmaline nodules withstand the decomposing action of the atmosphere for a longer time than the sur-

* H. Rosenbusch. Elemente der Gesteinslehre, p. 215.

rounding rock, and this causes them to stand out on the weathered surface, giving the rock a very remarkable appearance. From the same cause the subsoil in some localities is largely composed of these nodules.

Under the microscope the groundmass of the tourmaline aplites consists essentially of orthoclase, plagioclase, and quartz, with small quantities of both biotite and muscovite. The plagioclase is oligoclase-andesine, or albite. Measurements of extinction angles on sections cut approximately perpendicular to the twining lamellæ give results ranging from 9° to 16°. Some of the quartz appears to have preceded the felspar in order of crystallisation. Some of the grains have defined crystal edges, and they often protrude into, or are included in, the felspar crystals. Like the tourmaline granites, the quartz contains no microscopic rods of tourmaline. One section was prepared, showing the junction between a quartz tourmaline nodule and the surrounding rock. As the centre of the slide is approached, grains and hypidiomorphic crystals of tourmaline make their appearance; they are, for the most part, yellow-brown in colour, and show faint pleochroism. As the centre of the nodule is approached, the felspar—which is almost entirely plagioclase—dwindles, and the rock appears to be entirely constituted of quartz and tourmaline. The quartz occurs sometimes in the form of hypidiomorphic crystals surrounded by tourmaline, which is almost entirely without crystal boundaries; the tourmaline is blue in colour, and moderately pleochroic.

Other slides of nodules show an intensely pleochroic tourmaline of blue colour; the crystals are sometimes of tabular habit, and enclose grains of quartz in such a manner as to give rise to a pœcilitic structure. A small amount of much-altered plagioclase felspar is also present; it has preceded the tourmaline in the order of crystallisation. Rods of tourmaline are absent from the quartz of these nodules. Although not observed in the slides, a small quantity of tin oxide appears to be always present in the quartz tourmaline nodules. A small prospect was always obtained by crushing and vanning the stone, while a bulk assay taken from the nodules occurring at the Federation Mine yielded 0·2 per cent of metallic tin.

The tourmaline aplites may be said to differ from the tourmaline granites in the following particulars:—

(1.) They are finer grained.

(2.) They contain quartz tourmaline nodules in greater abundance, and in larger and more perfectly developed spheres.

(3.) Some of the quartz has preceded the felspar in order of crystallisation. The structure may be described as partly panidiomorphic.

Normal Aplites.

Many of the aplites do not contain quartz tourmaline nodules. They occur in the form of dykes in the normal granite and in the tourmaline granite, and as masses and nodules in the normal granite. One case was observed in which a small dyke of aplite contained a central seam of large crystals of quartz and felspar (pegmatite) with small cavities or druses, into which the crystal faces project. In many other cases miarolitic cavities were observed irregularly distributed through the dykes. Microscopically, the normal aplites closely resemble the groundmass of the tourmaline aplites. They are somewhat even-grained rocks, composed essentially of orthoclase, plagioclase felspar, with a little biotite and accessory tourmaline and apatite. The felspars are much decomposed; the plagioclase felspar, which is relatively less abundant than in the normal granite, appears to be oligoclase-andesine, or albite, and has preceded orthoclase in order of crystallisation. The quartz is more abundant than in the normal granites, and in some cases the grains carry rods of tourmaline quite similar in appearance to those described in connection with the normal granite. Their disposition is very capricious, as they are numerous in some grains and quite absent from others. The biotite shows bleaching and resorption phenomena; apatite occurs as an inclusion in biotite. Some of the quartz has defined crystal edges; it also appears as eyes in the orthoclase. When present in the latter form, tourmaline rods are absent.

Quartz Tourmaline Reefs.

The rocks which have now been described form in part the wall rocks of numerous quartz tourmaline reefs which occur throughout the district. We propose to use the term "reef" in the sense in which it is used locally, and by most mining men in Australia, viz., to denote any non-clastic tabular deposit composed largely of silicious material irrespective of its supposed mode of formation. Until comparatively recent years the filling-matter of fissures was regarded as being divisible into two well-defined classes—one formed by cooling from a molten condition, the other formed by precipitation from aqueous solution; and these classes are still known as dykes and veins respectively. It is, however, now generally conceded that it is impossible to draw any sharp line of division between these two types, and our investigation of the quartz tourmaline rocks of the Heemskirk district affords evidence of this fact. We find that there are both quartz tourmaline dykes and quartz tourmaline veins, and also types which occupy an intermediate position. As it is often difficult to decide at once to which class any given deposit belongs, it is evident that a general term is desirable, and the term "reef" appears to us to be quite suitable.

Quartz Tourmaline Veins.

It is a well-recognised fact that fissure veins are often not merely "fissures filled with mineral matter;" the material forming the vein may have been either deposited in an open cavity formed by the fissure, or it may have been deposited as a replacement of the wall-rock, or of some of the constituents of the latter. In the quartz tourmaline reefs of the Heemskirk district the greater part of the material has been deposited as a replacement of the wall rock, and only a very small portion as the actual filling of the fissure. These two portions of the vein we propose to distinguish by the terms "vein rock" and "vein stone," the former denoting that portion of the vein which has been formed as a replacement of the wall rock, and the latter that portion which has been deposited along the plane of the fissure, and generally in an open cavity.

The quartz tourmaline veins consist of tabular deposits composed essentially of quartz and tourmaline, traversing both the granite and the surrounding Silurian strata. There is a central seam or fissure filled usually with tourmaline, or quartz and tourmaline (the vein stone), and on either side of this is a granular rock composed of quartz, quartz and tourmaline, or quartz and white mica (muscovite or lithia mica) and tourmaline (the vein rock). Both the vein stone and the vein rock may carry tin oxide. The former is sometimes very rich in tin, the ore being often beautifully crystallised; in the latter the tin oxide occurs in crystalline grains, and is often finely disseminated. Pyrites appears to be an invariable constituent wherever the veins have been explored below water-level. It occurs in bunches in the vein stone, and also disseminated through the vein rock. In some cases the vein rock consists almost entirely of granular quartz and pyrite, the latter having the appearance of replacing the felspar of the granite. Besides those already mentioned, most of the other minerals which are of common occurrence in tin veins are present in small quantities, viz., bismuthinite, molybdenite (rare), arsenopyrite, chalcopyrite, galena, and zinc-blende (both of these rare, and in very small quantities), fluorite (in small quantities), and smoky quartz.

The vein rock differs very greatly in the amount of tourmaline present. Often it is composed almost wholly of quartz, but at other times the only quartz present appears to be that which formed the original quartz of the granite, the whole of the felspar being replaced by tourmaline. In other cases the felspar has been replaced by white mica, with or without the addition of quartz and tourmaline. The vein rock then forms a typical greissen. The tourmaline is of two varieties, the black or iron tourmaline and the green or alkali tourmaline. Although tin ore is associated with both varieties, the green tourmaline appears to be much the more favourable indication for tin.

The veins vary in width from a few inches up to 20 or 30 feet; in the latter case there are usually a number of parallel fissures filled with tourmaline running through the vein rock, and the mineralisation has evidently spread outwards from these fissures until the adjacent zones of replacement met in the centre. Often bands or lenticular bodies of unaltered granite exist within the reefs between two such zones. The veins generally run in parallel groups, but often there are several main directions of strike in the same locality. When the veins cross one another there is usually no faulting, pointing to the fact that the fissures were produced by contraction of the granite on cooling. The proof of the metasomatic nature of the vein rock is very conclusive, and may be deduced both from the field evidence and from the examination of thin sections under the microscope. When the veins occur in granite, the vein rock is granular, and the size of the grains is the same as that of the adjacent granite or aplite; there is no parting between the granite and the vein rock, the one seeming to pass over into the other. When the veins traverse sedimentary rocks, the vein rock, or metamorphosed wall rock, retains the original laminated structure. Original differences in porosity or composition have led to deposition of quartz along certain layers, and tourmaline along others, with the result that a black-and-white striped rock is produced, of very striking appearance. Perhaps the most striking field evidence of replacement is to be seen when a vein passes through a granite or aplite which is rich in quartz tourmaline nodules. The nodules are seen in the same abundance and of the same size in the vein rock as in the adjoining wall rock. When the nodules are absent from the wall rock, they are also absent from the vein rock. It is quite evident that the quartz tourmaline nodules, which consist of the same material as was contained in the solutions, were not attacked by them, but remained unaltered while the surrounding felspar of the granite or aplite was replaced.

Microscopic examination of the vein rock entirely confirms these conclusions. Two slides were prepared from a vein-stone poor in tourmaline, replacing granite, which contains quartz tourmaline nodules. The vein stone also contains nodules, but these were not sliced. Both slices are almost entirely made up of quartz, which is present in two forms. It occurs either as large grains, having the usual aspect of the quartz of the tourmaline granites (containing no microscopic rods of tourmaline), and as very small grains confusedly arranged, so as to produce a mosaic structure. A small amount of pleochroic hypidiomorphic tourmaline, enclosing small grains of quartz also occurs either entirely within or nearly surrounded by the mosaic quartz. The tourmaline and mosaic quartz are evidently replacements of the felspar of the granite. There is a tendency of the mosaic quartz to extinguish simultaneously over fairly well-defined areas. The junction of two such areas may be a straight line or an irregular line, suggesting strongly that the orientation of the quartz grains was conditioned by the position of the original felspar grains of the granite, the straight lines representing the contact planes of two adjacent members of a polysynthetically-twinned felspar.

Three sections were cut of quartz tourmaline rock replacing normal granite in which quartz tourmaline nodules were absent. These slides are composed of quartz, tourmaline, and a small amount of opaque matter, disseminated through the former mineral. The two types of quartz which have already been described as occurring in the quartz rock are also present in these slides. The large grains contain a little opaque matter and fluid pores arranged somewhat in linear fashion, and opaque rods of tourmaline showing radiant structure of exactly the same nature as those described as occurring in the quartz of the normal granite. There can be no doubt that these grains represent the original quartz of the granite. The mosaic or secondary quartz is of the same nature as that described in the quartz rock, but is less abundant, and in one of the slides is absent. The tourmaline occurs as idiomorphic crystals of prismatic habit in the secondary quartz, and as confused, ragged masses, sometimes fibrous in structure, and then showing tendency to radiant arrangement. We believe that this tourmaline is a replacement mineral after felspar and biotite, no trace of either of which minerals can be seen in the slides. Contrary to what was observed in the case of the replacing quartz, however, the felspar crystals have not determined any special orientation in the case of the tourmaline. In the slide in which replacing quartz is absent the original quartz grains do not seem to have entirely escaped change. They appear to be corroded around the edges, and to some extent replaced by tourmaline; this appearance is nearly absent from the slides, which contain secondary quartz.

One slide was prepared of greissen, occurring as a replacement of a granite or aplite, containing quartz tourmaline nodules. The rock consists of quartz, tourmaline, and a fibrous mica; the quartz appears for the most part in the form typical of the quartz of tourmaline granite, but there is in addition a small number of minute grains of quartz surrounded by a confused mesh of mica; the mica is in fibrous crystals, sometimes arranged with radial structure; it shows no pleochrism, but there is a considerable amount of absorption of light as the slide is rotated. It polarises in very high colours, and appears to have the optical properties of muscovite. Tourmaline occurs in small quantities as hypidiomorphic pleochroic crystals, but it is not present in the form of rods in the quartz grains. The mica would appear to be for the most part a replacement after felspar, but the occurrence of small nests and meshes of mica in the larger grains of quartz shows that the latter mineral has also suffered replacement. In the slide are a few very minute crystals of a highly refractory substance, which may be zircon; the material of the slide surrounding these specks is frequently coloured brown. One slide was prepared of quartz tourmaline rock, replacing slate which appears originally to have possessed a finely laminated structure. The laminæ have been for the most part replaced by grains of pleochroic tourmaline arranged linearly, and are separated from each other by minute grains of clear quartz.

The vein stone was not examined microscopically. It often consists almost wholly of tourmaline, but is sometimes very rich in tin oxide. The tourmaline often occurs in large bunches of radiating prisms or needles going up to 6 or 8 inches in length. Occasionally, however, a good deal of quartz is present, and this is especially the case where the veins traverse the sedimentary rocks. The tourmaline appears to gradually decrease as the distance from the granite increases, until finally only quartz veins are to be seen. With the disappearance of the tourmaline, disappears also the metamorphism of the wall rock, which is so characteristic of the veins, both in the granite and in its immediate vicinity.

Quartz-tourmaline Dykes.

These interesting dykes were, we believe, first observed by Mr. F. J. Ernst. They are found traversing both the granite and the sedimentary rocks, and are distinguished from the veins by the fact that their structure is not dependent upon the character of the wall rock, since they traverse granites, aplites, and sedimentary rocks without undergoing change. They have no central fissure, and the walls are generally sharp and clear-cut, even more so than the aplite dykes. They are usually of uniform composition throughout, consisting of a somewhat finely granular mixture of quartz and tourmaline, with sometimes a little felspar. When they traverse sedimentary rocks, they often contain included angular fragments of the country-rock. In the slides of this rock which were prepared the only minerals observed were quartz and tourmaline. The former mineral occurs as irregular grains, containing a very small amount of minute opaque specks. Tourmaline is present in well-formed crystals of prismatic habit, as grains, and as clusters of grains and crystals. The larger crystals of prismatic habit have a marked pleochroism, but as the crystals dwindle in size the pleochroism gradually diminishes, and cannot be detected in the smallest crystals. The tourmaline has preceded the quartz in order of crystallisation; radiating prisms of small size frequently penetrate the quartz grains, the centre of radiation being often one of the larger tourmaline crystals. The tourmaline rods previously alluded to are quite absent from the quartz of this rock.

In many cases the wall rock of the dykes has suffered metamorphism in a similar manner to that of the tourmaline veins, but to a lesser extent. In several instances, where the dykes occurred in granite, it was observed that the latter had been converted into quartz-rock or quartz-tourmaline rock, for a short distance (generally not more than a few inches) on either side of the dyke. In other cases, even along the same dyke, the wall rock had remained apparently unaltered. It is conceivable that this metamorphism may have been produced by vapours which traversed the fissure, prior to the introduction of the quartz-tourmaline magma, but it seems more probable that it was caused by emanations from the dyke-rock itself.

Two interesting instances of variation in composition were noted in the dykes traversing the Silurian strata at the Gentle Annie Rise, to the east of Mount Heemskirk. In one case of a dyke $2\frac{1}{2}$ inches in width, a portion of the tourmaline had segregated towards the centre of the dyke and formed a central seam about $\frac{3}{4}$ inch in width, the remainder of the dyke being composed of the normal quartz-tourmaline mixture. In another case of a somewhat larger dyke, the quartz had segregated, and for a foot or fifteen inches the dyke channel was filled with white quartz almost free from tourmaline. The latter instance seems to point to the fact that the quartz-tourmaline dykes may change to quartz veins as well as the quartz tourmaline veins.

Several observations were made at the Gentle Annie Rise of small quartz and quartz-tourmaline veins being cut through or faulted by quartz-tourmaline dykes. These observations are perhaps not yet sufficiently numerous to establish the relative ages of the two kinds of reefs definitely, but it may be said, that in some cases at least, the dykes are younger than the veins. This conclusion is of great importance, for it proves that the quartz and quartz-tourmaline veins were formed before the close of the period of eruptive action of the granite.

Conclusions.

We may now state briefly the conclusions which we think are justified by the facts which were observed in this district with regard to the origin of these tourmaline rocks and the associated tin-bearing veins.

It appears perfectly evident that the tourmaline is an original constitutent of the granite magma, since in one form or another it is contained in all the rocks which have been examined. There appears, however, to have been a continued tendency for the tourmaline to segregate together and separate itself from the rest of the magma. In the normal granite, it occurs only in microscopic rods in some of the quartz, and must represent an extremely small percentage of the total composition of the rock. But even here there is a tendency for the tourmaline to come together and form minute bundles of interlacing or radiating rods. In the tourmaline granites, the tourmaline is much more abundant, and forms macroscopic bundles of radiating needles, and even granular nodules of quartz and tourmaline. This great increase in the amount of tourmaline present is, we believe, to be accounted for by some process of differentiation or segregation in the original granite magma, while the presence of tourmaline in separate bundles and nodules may be accounted for by a further process of magmatic segregation from the already differentiated tourmaline-bearing magma. The tourmaline-aplite magma may have separated from the tourmaline-granite magma in the same way as the tourmaline-granite magma separated from the normal granite magma. The presence of irregular masses of tourmaline-granite in the normal granite, and of tourmaline-aplite in tourmaline-granite, is we think, convincing evidence that the three types of rock have originated from one and the same magma, and that the differentiation has taken place before, and not after, the consolidation of the magma. A definite order of consolidation of the three rocks may be observed. Dykes of tourmaline-granite occur in the normal granite, but not in the tourmaline-aplite, while dykes of tourmaline-aplite occur both in the tourmaline-granite and in the normal granite. It is evident therefore that the order of consolidation was (1) normal granite, (2) tourmaline-granite, (3) tourmaline-aplite.

The composition of the quartz-tourmaline nodules at once suggests that the quartz-tourmaline reefs are in some way connected with these. In many places the nodules appear to have a tendency to come together and unite to form larger masses of quartz-tourmaline rock. At greater depths, where the cooling of the magma would proceed more slowly, this might well take place, and the quartz-tourmaline magma thus formed might be the origin of the quartz-tourmaline dykes. The presence of the veins, however, suggests that a further separation first takes place within the quartz-tourmaline magma, namely, a separation into a highly aqueous and a less aqueous magma. The former would be virtually a saturated solution, and in this would be concentrated the heavy metals originally contained in the magma, since, from the common occurrence of these metals in mineral veins, we know them to be specially soluble in heated waters. Assuming, now, that such masses of quartz-tourmaline magma were intersected by fissures formed by the contraction of the granite in cooling, the more highly aqueous portion, being the more fluid, would be first erupted, and owing to its highly-heated condition and the presence of such powerful mineralising agents as boron, fluorine (both of these are present in tourmaline), hydrogen sulphide and water would have a very powerful chemical action on the wall of the fissures, producing the complete metamorphism of the wall rock, which has already been described. The more viscous quartz-tourmaline magma might be erupted later and form quartz-tourmaline dykes.

It will be remembered that the quartz-tourmaline veins traverse both the normal granite and the tourmaline granite and aplites, while in several instances the quartz-tourmaline dykes were observed to fault the quartz-tourmaline veins. The relative ages of all of the tourmaline-bearing rocks, described in this paper appear therefore to be as follows,—(1) normal granite, (2) tourmaline-granite, (3) tourmaline-aplite, (4) quartz-tourmaline veins, (5) quartz-tourmaline dykes.