The Tourmaline Copper Veins in the Yakuōji Mine, Nagato Prov., Japan.

By

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The western portion of the main island of Japan (Honshū) which is generally called “Chūgoku” by us contains numerous ore-deposits connected with granitic and dioritic irruptions during the Older Mesozoic Era. There are many contact-metamorphic deposits formed at the just contact between the eruptives and the sedimentaries (chiefly of Palaeozoic age).⁽¹⁾ Besides these, there are many interesting deposits, which do not exist at the contact place but near the contact in the sedimentaries or in the eruptives themselves, and which are evidently genetically related to the irruption of the igneous masses. They are all characterized by the presence of some contact minerals such as garnet, hedenbergite, wollastonite, tourmaline and others often associated with ores characteristic to the contact-metamorphic deposit and the tin vein type.

The deposits of the Yakuōji mine,⁽²⁾ which are now to be treated, are veins formed near the contact between a monzonite stock and the Palaeozoic sedimentaries—but mostly in the former, characterized by the presence of tourmaline as the chief gangue mineral.

The mine is situated about 3 kilometers east of the town of Ōda in Prov. Nagato and about 12 kilometers west of the town of Yamaguchi, the provincial capital. Economically considered, it is a very

(1) N. Fukuchi: Mineral Paragenesis in the Contact-metamorphic Ore-deposits Found in Japan. Beiträge zur Mineralogie von Japan, herausgegeben von T. Wada. Nr. 3. 1907 pp. 75-109.

(2) A brief note on this mine was given by Messrs. T. Hirabayashi and N. Fukuchi in 1904—Journ. Geol. Soc. Tokyo Vol. XI. pp. 63-64 (in Japanese). Also, a brief description of this mine was made by Dr. T. Suzuki in 1907—The explanatory text to the Yamaguchi sheet (in Japanese).

insignificant copper mine, the production of copper in the recent years being as follows :—

1911	175,785	pounds	copper						
1910	153,393	"	"	and	460	tons	5%	copper	ore
1909	120,099	"	"	"	870	"	"	"	"
1908	75,614	"	"	"	968	"	"	"	"
1907	94,229	"	"	"	1014	"	"	"	"

Geologically considered, however, it is very interesting, because it belongs to a rather rare vein type.⁽³⁾

Topography :—

The mine is located in a mountainous region of the mature age.

The characteristic topographic feature of Chūgoku⁽⁴⁾ due to the

(3) Veins with more or less tourmaline as vein stuff have been described and discussed among others by the following authors :—

A. v. Groddeck : Ueber Turmalin enthaltende Kupfererze von Tamaya in Chile. Z. d. D. G. G. 1887.

J. H. L. Vogt : Zur Classification der Erzvorkommen. Z. f. Pr. Geol. 1895 p. 149 et seq.

A. W. Stelzner : Ueber die Turmalinführung der Kupfererzgänge in Chile. Z. f. Pr. Geol. 1897 p. 41 et seq.

E. Fussak : Die goldführende, kiesige Quarzlageregang von Passagem in Minas Geraes, Brasilien. Z. f. pr. Geol. 1898. p. 349.

W. Lindgren : Metasomatic Processes in Fissure-Veins. Transac. A. I. M. E. Vol. XXX. 1900. p. 626 et seq. (also The Genesis of Ore-Deposits. 1902 pp. 546-564)—American occurrences of tourmaline-bearing veins are described in this paper.

H. V. Winchell and A. N. Winchell : Note on the Blue Bird Mine. Econ. Geol. Vol. VII. 1912. pp. 287-294.

(4) Prof. B. Kotô : The Physiographic Type of Chūgoku (in Japanese). Publications of the Imp. Earthq. Inv. Committee in Japanese Language No. 63. pp. 1-15.

According to his explanation, almost whole Chūgoku was reduced to a peneplain during the later period of the Mesozoic Era, which, during the early period of the Tertiary was gradually uplifted to an average height of 450 meters or more (typically recognized in the eastern and central Chūgoku). Consequently the rejuvenated streams and rivers began to be active again. Thus, since the Older Tertiary Period, Chūgoku, especially the region now forming the watershed between the rivers running southward and northward, was under the continued erosion and on the other hand the accumulation of disintegrated rock materials took place continuously in estuaries etc. until the end of the Tertiary Period was reached. At or toward the end of the Tertiary Period a disastrophic movement took place in Chūgoku, and resulted a warping of the ground over 100 meters—the Tsuyama basin which is now about 100 meters above the sea level, was certainly an estuary in the Younger Tertiary sea; the existence of the fossiliferous sediments which cover the basin suggests it.

repeated elevations and continued erosion is prevailing in this region too. At least, two geographical cycles are recognized in the vicinity of the mine. The older cycle is represented by the high mountains from 500 to 700 meters or over above the sea level, which make a rugged mountain region on the north and northeast of the mine. Mt. Mitsugashira (533 m) at whose southern foot the mine is situated belongs to this cycle of erosion. The younger cycle is represented by the lower mountains with a height from 150 to 300 meters or more. The region belonging to this cycle is very extensive in area and probably represents the peneplain formed during the Older Tertiary Period. Some part of the latter region, especially the limestone terrain, is remained now as an undulated plateau or an elevated peneplain of 200 meters or over in height, while the other part is represented by a much dissected and lower mountainous region. The remains of the peneplain as a whole, however, can be traced more or less distinctly as observed from any

Fig. 1. Yakuōji Mine as seen from the south.

of the higher mountains, the rounded tops of the mountains extending away to the horizon like billows on the ocean.

Though the Yakuōji Mine is located thus in mature mountains, it is not very inconvenient in communication, because a highway leads to it from the railway station of Ogōri, about 12 miles distant on the south. Just below the mine to the south, there is developed a small alluvial plain, which has been formed by the meeting of several small streams (Fig. 1.). The alluvial plain is immediately narrowed on the southwest of the mine, and the stream makes a small but deep gorge there—a characteristic young valley which is probably due to the elevation of the ground at the Younger Tertiary Period.

Geology :—

The alternation of graywacke sandstone, hornstone, limestone and clay slate of the Upper and Middle Chichibu System (Palaeozoic)⁽⁵⁾ and the phyllite and pyroxenite complex of the Lower Chichibu System (Lower Palaeozoic) are developed extensively in this part of Chūgoku. The two complices have the same strike of NE, but they are not conformable, because they are separated by a fault. At a certain period of the Mesozoic Era (probably the Older Mesozoic Period), a great monzonite mass intruded through the boundary between the two complices, which were metamorphosed by it more or less.

In the mine, only the monzonite and the Younger Palaeozoic sedimentaries are developed, which make their contact at that place. The sedimentary rocks there in the mine are represented by the alternation of arenaceous rocks—graywacke sandstone and slaty sandstone—, the latter being commonly so dark in colour that it is called there by the name of slate. The contact phenomena in the

(5) See "Outlines of the Geology of Japan : Descriptive Text to Accompany the Geological Map of the Empire on the Scale 1:1,000,000. Compiled by the Imp. Geol. Survey of Japan" pp. 18-19 and 33-48.

sandy rocks due to the monzonite intrusion are not very remarkable. Fritting, however, is characteristic, so that by the unaided eye the dark coloured metamorphosed slaty sandstone is easily mistaken for a hornfels originated from a clay slate, while the light coloured sandstones have been changed into whitish or light greenish compact rocks. Microscopically, the original sandy character is well revealed. Quartz and feldspar grains have not been much affected, while the clayey cementing matter shows evidences of more or less recrystallization, often consisting of minute grains of feldspars, irregular flakes of biotite, sericite, chlorite, graphite etc.

The metamorphosed sandstones and sandy slates near the contact place with the eruptive rock, which are black, white or green in colour, are often traversed by innumerable minute green veinlets along which the rock is usually bleached. Under the microscope the veinlets consist chiefly of chlorite flakes but rarely mingled with tourmaline. The latter mineral is found as irregular minute patches *replacing feldspar grains partially or entirely*.

As the profile (Plate I.) shows, the monzonite mass is widely extended below the surface, and therefore as we proceed from the surface of the slope through the adit levels in the monzonite, we are always met with the contact plane between the eruptive and sandy rocks at a distance much further than that on the surface.

Monzonite shows a coarse granular structure with a more or less dull luster even when comparatively fresh; perfectly fresh one can not be found in the environs of the mine. Feldspars and hornblende, the two chief ingredients, attain sometimes a size of more than 1 cm, the latter showing usually a long prismatic habit. Of feldspars, we can readily distinguish two varieties even with the unaided eye. The one is more largely developed and has a light bluish colour with a resinous luster; it occupies the greater bulk of the light coloured ground. The other is crystallized in much smaller forms.

and is scattered in aggregations commonly occupying the spaces between the former. It is usually white or light pinkish in colour and translucent.

As determined under the microscope, the larger and light bluish feldspar is a plagioclase with characteristic polysynthetic twin-lamellae and sometimes a zonal structure. It belongs to the labradorite family as determined by the methods of Fouqué and M. Schuster. The white and pinkish variety is orthoclase which occurs commonly in xenomorphic and hypidiomorphic forms but sometimes in an idiomorphic crystal with or without the Carlsbad twin. The labradorite is always of earlier crystallization than the orthoclase. The orthoclase is commonly much kaolinized and turbid even when the labradorite remains freshly. Quartz which is macroscopically rather sparingly seen, occurs in minute round or angular grains imbedded chiefly in orthoclases. It is very characteristic that quartz does not occur alone as xenomorphic mesostasis, as the com-

mon case in granites and diorites is, but fills up the interspaces of the larger plagioclase crystals altogether with orthoclase often in micropegmatitic intergrowth—a structure common to syenitic rocks.⁽⁶⁾

Hornblende occurs in well defined large prismatic crystals often attaining a size of more than 1 cm along the vertical axis. It is a common hornblende

Quartz Monzonite. $\times 30$. + Nicol.
p = Plagioclase (Labradorite)
o = Orthoclase
h = Hornblende
Q = Quartz

(6) H. Rosenbusch : Mikroskopische Physiographie der Mineralien und Gesteine. Bd. II. 1907. pp. 174 and 176.

rich in iron, and, when fresh, shows a strong pleochroism as follows:—

a = oil-yellow b = brownish green c = dark greenish brown

The alteration of hornblende to chlorite is very common, especially near the selvage of the veins, as will be stated fully in the subsequent article. The hornblende is faded to green in colour, when has suffered more or less alteration. It is the intermediate stage between the brownish green hornblende and the chlorite, and that stage is prevailing in the monzonite in the environs of the mine.

Biotite occurs rather sparingly in well defined six-sided plates with a diameter of 1 mm or less. It is sometimes altered into chlorite too.

Fine needles of apatite, well developed minute crystals and rounded grains of zircon, and small crystals and grains of magnetite are the common accessory minerals. The zircon crystal and grain, when enclosed in the hornblende, show a typical pleochroic halo.

Very rarely, allanite is found in well bounded prismatic crystals (elongated || b) with a length less than 1 mm. It is distinctly pleochloic (deed brown to brown).

Thus the rock under consideration is a quartz monzonite.

Ore-Deposits:—

The ore-deposits which are worked in this mine belong to the fissure filling vein, formed near the contact place between the monzonite and the Palaeozoic sandy rocks, penetrating chiefly the former but sometimes the latter too. There are many parallel veins with a strike of NS (often slightly deviating to E and W) and a steep dip of 70° or more usually towards E but rarely towards W. The number of veins, so far found, is eleven, out of which only six are now being worked; more veins will be found there by the further cross-cutting. The veins are commonly very thin varying from a mere streak up to 2 feet or a little more in maximum. The country rock near the veins is generally more or less impregnated

with sulphide ores and the veins sometimes branch into stringers. Two principal veins, which are now chiefly worked, are the Shinkō-no-Hi (New adit vein) and the Kyūkō-no-Hi (Old adit vein). The former attains sometimes a thickness of 2 feet (commonly less than 5 inches), but *the workable impregnated zone with branched stringers and parallel veinlets* attains frequently a width up to 20 feet.

The Cause of Vein Fissures:—

As already mentioned, the vein fissures in this mine are confined chiefly to the monzonite mass all in the parallel direction of NS sometimes deflecting 10 or less degrees to the east and west directions. Near the contact plane with the sedimentaries the veins usually diminish in width and ore-content, and gradually pass into dark streaks. Very rarely the vein is continuous through the sedimentaries, but in this case it would suddenly become thinner and poorer and soon diminish into streaks and then disappear. There is no indication of displacement of the walls along the vein fissures, the fault plane (clay vein with a remarkable displacement of walls) being but rarely observed across the parallel veins. Moreover, as will be later fully discussed, the veins are evidently of pneumatohydatogenetic origin, which process is considered to take place just after or during the consolidation of the igneous mass. The vein fissures here considered are thus undoubtedly due to the contraction of the monzonite mass as in the case of Klovereid veins in Telemarken (Erzgänge auf Spalten (senkrecht stehende Absonderungsspalten) innerhalb der Granitmassive).⁽⁷⁾

Though the contraction fissure is usually limited to one kind of rock, and not continuous to the neighbouring one,⁽⁸⁾ it is evident that the sedimentary rocks near the contact place with an eruptive intrusion undergo a remarkable volume change due to the contact-metamorphism. Thus the contraction of the igneous and sediment-

(7) J. H. L. Vogt : Z. f. Pract. Geol. 1895. pp. 149-150.

(8) F. Pošepný : Ueber die Genesis der Erzlagertstätten. 1895. p. 102.

ary rocks altogether may result fissures continuous in the two kinds of rocks. This is the case with the Yakuōji veins.

The Vein Filling:—

The chief ore is chalcopyrite which occurs commonly in masses, patches, streaks etc. Other sulphide minerals found there, are arsenopyrite, pyrites and bismuthinite. The two former minerals occur usually in small crystals, and rarely in small irregular masses. The last one is found usually in small irregular patches often commingled with chalcopyrite masses. Besides, small irregular masses of native bismuth are found very rarely, and still more rarely bismuthinite masses with a bismuth nucleus in center have been observed. Galena and zincblende occur very rarely and sparingly in irregular grains and masses.

The most remarkable gangue mineral is tourmaline which occurs in slender prismatic crystals often with well-developed hemimorphic terminal faces or more commonly in aggregations of fine needles with a radial or stellated structure. The tourmaline prism has a width commonly of 0.04 mm or less, and only rarely of 0.3 mm, while the stellated aggregation of needles often attains a diameter

Fig. 3.

Tourmaline Stellate imbedded in
Quartz. $\times 25$. Polarizer only.
T = Tourmaline
Q = Quartz

of 1 cm. It is, macroscopically, dark black in colour. In thin sections, it shows the characteristic pleochroism—violet yellow $\parallel \hat{c}$ and quite dark to violet blue $\perp \hat{c}$. Zonal structure is frequently observed especially in the transverse section of it, and then the outer border of the bitrigonal outline is always darker in colour than the inner part.

The important gangue mineral next to tourmaline is chlorite. It occurs in aggregations of irregular minute flakes, rarely of six-sided minute scales. It is macroscopically dark green, but microscopically it shows a beautiful green colour often with distinct pleochroism (greenish to yellowish). Besides, minute spherulitic aggregation of chlorite fibers is sometimes observed, which under the crossed nicols shows a distinct cross-bar. The chlorite is easily recognized by its colour, weak double refraction and other properties. In most cases, it occurs intermingled with more or less fine tourmaline needles.

Scheelite represents sometimes an important gangue mineral⁽⁹⁾ in the Yakuōji vein. It occurs commonly in well developed crystals, although it is very difficult to separate it out owing to the fact that it is imbedded firmly in the chlorite-tourmaline mixture, sulphide ores and other minerals. The cross section of the mineral shows a rhombic form (PL. II. Fig. 2.) due to the predominant development of pyramids, though sometimes it is distorted. The size of the mineral varies from a few millimeters up to 4 centimeters in the direction of the vertical axis, the commonest size being 1 to 2 centimeters. It is characterized by the distinct cleavage parallel to P, uneven fracture, white to yellowish white colour, resinous luster etc.

Quartz plays sometimes a very important rôle as vein stuff and occurs most commonly in massive state, and but rarely in crystals with predominant prismatic faces. Minute liquid enclosure with a bubble is very commonly and abundantly found in quartz, when observed with an objective of high power.

Calcite occurs very sparingly in small patches and streaks usually in the tourmaline and chlorite ground.

The Yakuōji veins are not everywhere uniform in mineralogical composition and structure. In some places, it is chiefly composed

(9) Scheelite is here considered as a gangue mineral but not an ore, because it does not occur there in such a quantity as to be worked with any profit. sometimes, however, it is found in a good quantity, being concentrated locally in the veins as the specimen shown in PL. II. Fig. 2.

of stellated aggregations of black tourmaline fibres and massive quartz with a small quantity of chalcopyrite, which is scattered irregularly in patches and streaks in them, and often fills the spaces between the tourmaline stellates (PL. II. Fig. 1.). Other sulphides such as pyrites, arsenopyrite, rarely bismuthinite are sparingly associated with copper pyrite. The tourmaline stellates are imbedded in the quartz ground. Calcite occurs very sparingly as fillings of small cracks. The tourmaline is therefore of earlier crystallization than the sulphide ores, quartz and calcite. This kind of vein portion is sometimes represented by a barren quartz-tourmaline vein in which the tourmaline stellates are imbedded in quartz (Fig. 4.) and the sulphide ore is often entirely absent. In other places,

Fig. 4. Barren Tourmaline-Quartz Vein.

a = altered monzonite
b = chlorite-tourmaline mixture
c = quartz
d = tourmaline

the vein is characterized by the presence of abundant scheelite and chlorite, the latter being commonly commingled with more or less quantity of tourmaline. They are always accompanied by a good quantity of sulphide ores and a small quantity of quartz, and in general this portion is much richer

than the first case as a copper ore. Among the sulphide ores, chalcopyrite is predominant, iron pyrites, arsenopyrite and bismuthinite are associated in less and varying quantities. Sulphides, chloritic matter, quartz and all other constituents except tourmaline are often *apparently* enclosed in scheelite, but on a closer examination, we will find that all these minerals belong to the later crystallization and were impregnated and infiltrated along the cracks and cleavage fissures of it. (PL. II. Fig. 2).

The third type of the vein portion is composed entirely of massive

Fig. 5. Massive Chalcopyrite Vein.

a = altered monzonite
b = chlorite-tourmaline mixture
c = chalcopyrite

chalcopyrite with no vein stuff. It is, however, always bordered with chlorite selvages mixed with a little quantity of tourmaline (Fig. 5.).

Generalizing the above mentioned facts, the scheelite and the tourmaline belong to the earliest crystallization of all. The vein

as a whole, however, shows a massive structure and no banded structure. In other words, it shows no trace of remarkable reopening nor of succeeding ascension of different solutions. There is no room for doubt that the vein has been formed by one and the same mineral solution saturated with mineralizers such as boron etc., and that the crystallization has been begun at first by scheelite, tourmaline and chlorite (the two latter minerals are due to the metasomatic action as explained in the next article), which have been succeeded by quartz, calcite and sulphide ores—chalcopyrite, pyrites, arsenopyrite and bismuthinite with a very little of native bismuth, the well developed crystals of iron pyrite and arsenopyrite being due to the more powerful crystallizing tendency than the others.

The Metasomatic Operation of the Mineral Solution:—

It is not probable that in the monzonite and the neighbouring sandy rocks so wide fissures, as now exist as veins, were formed by the contraction of the magma. Moreover, the widest vein is not always continuously wide; sometimes it diminishes in width to a mere stringer and at other times it branches to a group of stringers forming a very wide but poor workable portion of the

deposit. There are many unworkable thin veins, as already stated, with chlorite-tourmaline gangue impregnated with a little sulphides, and those veins pass very often gradually into the dark green chloritized monzonite on both sides, while some of them are rather sharply bounded from more or less chloritized monzonite. It is certain that the fissures there formed were only such as to admit the passage of the mineral bearing water. The water attacked the rock on either side of the fissure, and, by a process of metasomatic replacement, deposited ores in the place of the simultaneously dissolved rock constituents.⁽¹⁰⁾ Thus the rock adjacent to the fissures must have been first attacked and replaced by the pneumatolytic process, the solution having been comparatively rich in the boron-mineralizer. At last the process was arrested and the boundary was left relatively sharp, however the hydrothermal alteration have proceeded further. After the explanation of J. D. Irving,⁽¹¹⁾ this process is the replacement which has advanced like a wave over the country rock until its termination has arrested it at some point. If the process has operated in this way the advancing solution must have found their way constantly through the newly formed mineral-aggregation and as this is generally quite porous, due to the innumerable little cavities left by the decrease in volume, it has probably gained access to the outer wall in this way. These volume vugs are often filled up by crustified linings of minerals which have been deposited from the ore solution. The structure resembling the incrustation assumed by the tourmaline stellates and the quartz, which is rarely observed in the Yakuōji veins, may be explained in this way (Fig. 1. Pl. II.).

The tourmaline is thus of pneumatolytic metasomatic origin, and the chlorite is a product of the hydrothermal replacement.

(10) S. F. Emmons: The Genesis of Certain Ore-Deposits. Trans. Amer. Inst. Min. Eng. XV. 1886. p. 146.

(11) J. D. Irving: Replacement ore-bodies and the criteria for their recognition: Econ. Geol. Vol. VI. 1911. p. 558.

The latter process naturally has longer continued than the former, and therefore the country rock has been further altered by the later process,⁽¹²⁾ and sometimes even the already formed tourmaline has been affected by it.

The Alteration of the Tourmaline:—

Tourmaline is one of the most resistant minerals, but it is known to alter in some cases to muscovite, lepidolite, biotite, chlorite, steatite etc.⁽¹³⁾ The alteration of tourmaline into chlorite, however, is much rarer than that to micas.⁽¹⁴⁾ Tschermak says in his conclusion that “den zahlreichen Funden von aus Glimmer bestehende gegenüber, was zu dem Schlusse berechtigt, dass die letztere Pseudomorphose (Chlorit nach Turmalin) relative selten sei.” In the Yakuōji veins, the alteration of the vein forming tourmaline into chlorite is very characteristic. As observed under the microscope, the tourmaline needles and stellated aggregates especially those in the chlorite-tourmaline vein stuff are often converted into chlorite sometimes entirely and at other times only partially. When entirely altered, the chlorite shows often a radiated or stellated structure characteristic to tourmaline, or sometimes it assumes a slender needle-form after tourmaline. The form and the aggregation-structure of tourmaline assumed by the chlorite, however, if the alteration has advanced further, have become indistinct and graded into irregular aggregations of scales and flakes (Fig. 6). When partially altered, there is every stage to be observed from the tourmaline aggregates or needles with very small portions altered to chlorite up to the chlorite aggregates or needles in the shape of

(12) See the subsequent article : The Alteration of the Monzonite.

(13) C. Hintze : Handbuch der Mineralogie. II. Band. p. 331.

J. D. Dana : A System of Mineralogy. 6th. ed. 1906 p. 557.

Van Hise : A Treatise on Metamorphism. p. 326.

F. W. Clarke : A Data of Geochemistry. Bull. U. S. G. S. No. 330, 1908. p. 347.

Brauns : Chemische Mineralogie. 1896. p. 415. etc.

(14) G. Tschermak : Die gewöhnliche Umwandlung der Turmaline. Tscherm. Min. Pet. Mitteil. Bd. 21. 1902 p. 1-14.

tourmaline with very little remnants of unaltered tourmaline. The

Fig. 6.

Tourmaline Stellate partially altered into Chlorite. $\times 25$. Polarizer only.

T = Tourmaline

C = Chlorite

partially altered tourmaline reveals that the alteration has begun always from the ends of the needle, and therefore in the case of the radial aggregation, the central part and the outer portion of the stellate have been changed into chlorite. The chlorite thus formed is dark green in colour in thin sections and shows a very weak birefringence, often characterized by distinct pleochroism ranging from

dark green to yellow. The pleochroic variety of chlorite with the shape of tourmaline needle shows sometimes the strongest absorption along the direction $\perp c$ of the needle and at other times $\parallel c$. In the latter case, the contrast between the tourmaline and the alteration product of it is remarkably exhibited especially when the partially altered tourmaline is considered, the direction of the strongest absorption of the two minerals being perpendicular to each other in one needle.

The ends of tourmaline needles are very rarely altered into a colourless substance with a well developed cleavage and a strong birefringence. It is very difficult to determine under the microscope owing to the smallness and the scarcity of the substance. There are, however, many facts to believe that it belongs to the family of muscovite, which is so common an alteration product of tourmaline.⁽¹⁵⁾

(15) C. Hintze : Handbuch der Mineralogie II. 1897 pp. 331-337.
Tschermak : Loc. cit. 1-14.

The alteration of the tourmaline here considered can not be ascribed to the action of the surface water, because the sulphide ores in this portion have not been affected at all. It is highly probable, therefore, that the alteration was due to the *action of the same solution as that which caused the formation of the tourmaline and which was active still longer after the loss of the mineralizer.*

Fine crystals of zircon, and more frequently rounded grains of that mineral are sometimes found as inclusions in the tourmaline stellate and in the alteration product of it. The pleochroic halo around the zircon is in some cases observed; it is especially remarkable when the mineral occurs as an enclosure in the chloritized tourmaline. The occurrence of zircon in the tourmaline vein has been described by Stelzner,⁽¹⁶⁾ Fussak⁽¹⁷⁾ and others, which is thought to have been formed simultaneously with the tourmaline and the ores from the mineral-bearing solution. In the case under consideration, however, it seems to the writer more probable to think that the zircon is the remnant of the accessory mineral of the monzonite which suffered the metasomatic action, as it is scattered sparingly and irregularly in the tourmaline-chlorite vein stuff and the size and the form of it are quite similar to those found in the rock.

The Alteration of the Monzonite by the Solution :—

The monzonite in which the veins are chiefly found has been subjected to the alteration by the mineral-bearing solution. The alteration is naturally most intense near the veins and gradually fades away into the comparatively fresh part within a short distance from them.

The rock grades into a macroscopically dull and lusterless variety with diminishing granular character towards the vein. Just near the selvage, the rock is commonly dark greenish in colour due to the alteration of hornblende to a dark green mineral, which is in this

(16) A. W. Stelzner : Loc. cit. p. 46.

(17) E. Fussak : Loc. cit. p. 345.

part no longer pseudomorphous after the hornblende crystal, but is scattered irregularly as grains and spots between dull white or pale greenish decomposition products of feldspars.

The boundary between the altered monzonite and the veins, as already stated, is in some cases relatively distinct, though in other cases the veins pass gradually into the altered rock on either side. By the microscopical examination of the rock near the vein, we know that the predominant labradorite crystal which looks a dull whitish or resinous light greenish substance usually with the original crystal form, is altered into an aggregation of very fine sericite scales. The orthoclase grains and crystals, which fill up the interspace of larger plagioclase crystals, are commonly changed into a dirty turbid mass with prevailing clayey and kaolinitic substances and more or less sericite scales. Alteration of feldspars into calcite is rather rarely observed. Quartz has not suffered the alteration at all, and remains quite freshly. It occurs with the decomposed orthoclase in a micropegmatitic intergrowth in the space between plagioclase crystals, as in the case of the fresh rock.

The most characteristic alteration of the rock forming minerals is the chloritization of hornblende. Hornblende crystals in the rock near the veins are almost entirely altered into chlorite, every stage of change being observed. Chlorite with the form and the cleavage of hornblende is commonly found, and when the alteration has proceeded further, the characteristic form of hornblende has gradually disappeared until at last it has been changed to an irregular aggregation of chlorite flakes.

Aggregations with a spherulitic structure, globulitic grains and minute scales with a hexagonal outline of chlorite are also developed in the much altered portion near the vein; they are, then, very irregularly scattered in the altered rock.

Impregnations of sulphide ores such as chalcopyrite, pyrites and arsenopyrite are fairly common. Chalcopyrite has no definite form,

while the two other ores occur usually in small crystals.

Silicification of the rock is only very rarely observed along the selvages ; that portion shows a mozaic structure composed of small quartz grains, abundant chlorite flakes and granules being enclosed in them.

Microscopic veinlets of calcite associated with chlorite and sulphide (chalcopyrite) grains are sometimes developed in the country rock near the chief veins, feldspars and hornblende along these filled up cracks being usually replaced by the above mentioned minerals, while the quartz remains quite freshly.

It is peculiar to find that the tourmaline is almost entirely absent even in the altered rock, though a few needles of this mineral have been observed in the rock just along the veinlets with much tourmaline. It is evident that the pneumatolytic action was arrested in a comparatively early stage of the vein formation, while the hydrothermal action has continued further and longer.

From the facts, stated in the last four articles, we can catch a glimpse of the nature of the solution by which the Yakuōji veins were formed and the country rock was changed. It was evidently rich in the boron-mineralizer and contained W, S, SiO_2 , Cu, Fe, As, Bi, H_2S , SO_3 , Na, K, with but little of Ca, Pb, Zn etc. in the form of either free or of various compositions. The solution was thus alkaline but comparatively poor in CO_2 or alkaline carbonates, since the carbonate gangue is very sparing in the veins and the carbonatization of the rock is practically unknown, while the sericitization of feldspars is universal.⁽¹⁸⁾

The Oxidized Zone of the Veins :—

The veins are usually capped by a narrow zone of oxidized ores. It is composed of limonite, cupriferous limonite (pitch copper ore), with a little amount of cuprite, malachite, chrysocolla etc. The

(18) W. Lindgren : Metasomatic processes in fissure-veins. The Genesis of Ore-Deposits 1903. p. 578.

gangue minerals except the quartz are decomposed into a ferruginous clayey matter. The oxidation zone is never accompanied by a remarkable secondary enrichment zone below, but commonly is underlain by the primary ore without a sharp boundary at a depth of 100 feet or less from the surface.

The Conclusion:—

The Yakuōji veins are “replacement veins”⁽¹⁹⁾ due to pneumatohydrogenetic origin.

The vein forming solution, which was alkaline and contained B, W, SiO₂, Cu, Fe, As, Bi, H₂S, SO₃, K, Na, Ca, Pb, Zn etc., appears to have originated from the consolidating monzonite and ascended through the contraction fissures in it.

The pneumatolytic agents in the solution attacked the rock on either side of the fissures very strongly and caused a more or less complete metasomatic conversion into tourmaline.

The hydrothermal metasomatism took place at the same time as the tourmalinization and has continued still longer after the pneumatolytic process ceased, the chief products of that action being the chlorite, the sericite and the kaolin.

While the solution has been attacking the rock metasomatically on the one hand, the deposition of minerals—scheelite, quartz, sulphide ores, native bismuth, calcite etc.—has taken place in thus widened fissures on the other hand.

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Explanation of Plate II.

Fig. I. Specimen of the Yakuōji Vein I. (Original in the Collection of the Meiji College of Technology). $\frac{1}{3}$ *natural size*.

(19) The so-called criteria for the replacement vein suggested by Emmons (U. S. Geol. Surv., Folio 38, on Butte, Montana) are all available in the veins under consideration.

This specimen represents the vein portion rich in tourmaline and poor in sulphide ores. The tourmaline (black) occurs in stellated aggregates imbedded in massive quartz (gray). In this portion of vein, the tourmaline and the quartz play the most important rôle in the vein filling, while the sulphide ores occur only subordinately as streaks and patches. In the middle part of the vein, almost parallel to the selvage, a banded structure is observed. The bands consist of aggregates of tourmaline stellates and are quite similar in composition to the environment of them. This structure resembling the incrustation is due to the formation of the mineral in the contraction spaces as explained on pages 81 and 82.

Fig. II. Specimen of the Yakuōji Vein II. (Original in the Collection of the Meiji College of Technology). $\frac{1}{2.5}$ natural size.

This specimen represents the vein portion rich in scheelite and sulphide ores. Near the selvages, chlorite-tourmaline mixture is well developed, while the middle part is occupied by abundant scheelite crystals (showing white rhombic section) and sulphide ores (chiefly massive chalcopyrite with subordinate bismuthinite, arsenopyrite and iron pyrite), the latter cementing the interspaces of the former. A little quantity of chlorite-tourmaline mixture is commingled with the sulphide ores too. Quartz occurs only subordinately in this portion with the sulphide cement and occasionally in the cracks of scheelite. The brightly shining part on the right upper side of the specimen is the country rock which is seen passing gradually into the chlorite-tourmaline gangue.