The Pyrrhotite Tin Vein of the Mitaté Mine, Prov. Hyūga, Japan.

BY

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Introduction :—

The tin production in Japan is insignificant, the most productive tin mines at the present time being the Taniyama mine in the province of Satsuma and the Akenobé mine in Tajima.⁽¹⁾

The Mitaté mine, which had been known as a tin mine for several centuries, but been abandoned until recent date, has been under prospect on a large scale, and is found to be a promising enterprise. It is now in preparation for communication, mining and smelting. Though it is situated in a rugged mountainous region, it is expected to grow into one of the most productive tin mines in this country in a few years. This mine is of special interest for geologists, because the ore-deposit worked there belongs to a rather rare vein type.

Topography and Geology :—

The rugged mountain mass in the eastern part of Middle Kyushū, including the southern portion of the province of Bungo and the northern portion of Hyūga, is the most mysteriously interesting region in the history of Japan, but now remains one of the remotest districts owing to its disadvantageous geographical

(1) The production of tin in the Taniyama mine during recent years has been as follows :—

1910	39712	pounds tin.
1911	40028	" "
1912	42243	" "

The total value of the dressed tin-ore (Containing about 50% Sn) produced in the Akenobé mine is estimated at 71,900 Yen in 1910, 196,600 Yen in 1911, and far over 250,000 Yen in 1912. The larger part of the tin-ore has been exported.

position. This mountain mass, composed of precipitous peaks of 1000 to 1757 meters (its culminating point being in Mt. Sobosan 1757 m.) and sculptured by deep valleys, may represent the typical mutural topography of Japan with later rejuvenated rivers.

The Mitaté mine lies in this mutural mountainous district, and is about 14 kilometers southwest of the village of Kiura in prov. Bungo and about 20 kilometers southeast from the village of Obira in the same province. These two villages were well known tin districts in the past. The village of Kiura is about 44 kilometers southwest from Saigi on the eastern coast of Kyushū, the nearest accessible harbour from the mine under consideration. The situation of the mine is on the northwestern flank of Mt. Goyōdaké (1569 m.) at a height of about 900 meters above sea level. It is along a small stream, running northwestwards and coming into the valley of the Hinokagé-gawa at a point 1 kilometer distant from the mine. The Hinokagé-gawa is a large tributary of the Gokasé-gawa, the largest river on the eastern slope of Kyushū, and is efficiently available for getting water-power.

Geologically, the mountain mass now under consideration is composed chiefly of Palaeozoic sedimentaries, much disturbed and complicately intruded by granitic rocks. Contact-metamorphism of the sedimentaries is often conspicuous, and numerous ore-deposits have been formed at the contact of the granites with the sedimentaries especially with limestones. Kiura and Obira, above mentioned, being the most famous ore-producing districts. Narrow zones along the valleys in this mountain mass are often covered by a thick layer of the dark lava which effused from the large crater of the volcano of Aso and flowed down along the large valley of the Gokase-gawa, dividing into branches on its way downward toward the tributaries of the river.

In the environs of the Mitaté mine, quartzite and limestone of

the Chichibu System (Upper Palaeozoic) and conglomerate of unknown age, probably of Younger Mesozoic age, are developed.

Fig. 1. Geological Sketch Map of the Mitate Mine
(Local Mesozoic Conglomerate Omitted)

Scale 1 : 25000.

Quartzite. Quartzite is the dominant rock in the vicinity of the mine. Varieties of this rock are recognized. The commonest variety is a fine grained quartzite with a whitish, grayish or light pinkish colour. It is remarkably sandy in appearance, and sometimes crumbles down into loose fine sand when attacked by atmospheric agencies. As microscopically observed, it is a metamorphosed sandstone. It is composed chiefly of minute grains of quartz (0.006—0.06 mm in diameter) with very fine scales of sericite and biotite scattered through the rock. Sometimes, large grains of quartz are scattered sporadically in the ground of finer grains, the former usually being clear without any contamination with micaceous scales. This variety of quartzite is sometimes

represented by a highly characteristic quartzite with a banded structure showing alternate stripes of thin, black and light coloured layers. The banded structure is sometimes very regular, being composed of stripes of almost equal thickness. Frequently, the stripes are so irregularly and intricately mixed and wrinkled that the rock reminds us of injection-schists. The light coloured layer is practically of the same character as the quartzite mentioned above. The black coloured layer, as examined in thin sections, has also essentially the same composition and structure as the light coloured one. It is, however, very rich in biotite scales, or rather full of them. Larger quartz grains are scattered in an aggregate of very fine quartz grains commingled with minute biotite scales and flakes, and more or less graphitoid particles (Pl. I. Fig. 1). The larger quartz grains are often distorted in form and crushed into several grains. Consequently, it is probable that the banded quartzite was originally a sandstone with intercalated laminae of shaly sandstone, which was contact-metamorphosed and later influenced by dynamic actions. The light coloured layer represents the original sandstone, while the black coloured one full of biotite and graphitoid represents the original shaly sandstone.

Near the ore-deposit, a compact flinty quartzite with a light grayish to gray colour is developed. As examined under the microscope, this rock is sometimes composed of almost equidimensional angular grains of quartz, 0.033—0.33 mm in diameter, showing a mozaic structure, while in some portions, the same rock consists of minute grains of quartz and cryptocrystalline silica with sporadic larger quartz grains in a phenocrystic size. The former part represents the recrystallized quartzite.

Limestone. A thick limestone, perhaps over one hundred meters in thickness, is intercalated in the above mentioned quartzite complex, as can be observed at the mine. It is medium-grained, saccharoidal crystalline variety, commonly pure white in colour,

but sometimes with a grayish, light bluish or pinkish colour. Owing to the crystalline character, it is apt to fall into loose grains by decomposition. Under the microscope, it is composed of calcite, nearly equidimensional in size with a diameter of 0.33 mm or more, and shows a typical mosaic structure. The grains are sometimes contaminated with very fine particles of graphitoid, limonitic substance etc., which colour the rock gray or pinkish brown respectively. The perfect cleavage and twin-lamellae due to the molecular gliding under the influence of pressure are very characteristic in the calcite grains. The limestone, as a whole, has undergone metamorphism and recrystallized due to the contact action that is universal in this district.

The quartzite-limestone complex has a strike of E—W and dips steeply toward the north, this strike and dip corresponding with the general strike and dip of the Palaeozoic System composing the Bungo-Hyuga mountain-mass.

Conglomerate. A conglomerate is locally developed in the environs of the mine, covering the quartzite-limestone complex unconformably. It is not a member of the Palaeozoic System, but is of later age, because it is composed chiefly of large and small gravels of granite, and of quartzite, limestone, clayslate and other Palaeozoic sedimentaries, developed in this district. The granite, being intrusions through the Palaeozoics, as will later be explained, is of Mesozoic age, and consequently, the conglomerate represents a deposition in the Younger Mesozoic Period.

The Ore-Bringer:—

As already stated in the previous article, the mountain mass, including southern Bungo and northern Hyūga, is composed essentially of Palaeozoic sedimentaries with granitic rocks intruded through them. Contact deposits abound, and contact metamorphism of the sedimentaries is often conspicuous. Granitic rocks, including granites, granite-porphyrries, quartz-porphyrries with all transitional

types, are extensively exposed along the provincial boundary in the form of large stocks. Besides, sporadical occurrences of the same eruptives in the form of small bosses, dykes etc. are observed in this district. They belong, though they apparently show conspicuous deviations in character and structure, to the same period of irruption and are derivatives from the same magma. For example, in the environs of the Obira mine, coarse and medium-granular biotite and two-mica granites, tourmalinized granites, quartz-porphyrries and others pass over one another, showing remarkable magmatic differentiation.

At the Mitaté mine, no eruptive rock is found, though granitic rocks are exposed at places not very far from it. For instance, near Kannegaharu, about 3.5 kilometers southwest of the mine, a small stock of a medium to coarse-granular biotite granite outcrops, which is well exposed along the valley of the Hinokage-gawa for a distance of about 2 kilometers. Another instance is a quartz porphyry in the form of thick dyke or small elongated boss with a width of about 500 meters, exposed on the western flank of the pass leading from Mitaté to Kiura, at a distance of 3 kilometers from the mine. This rock is the nearest eruptive to the Mitaté mine, and is evidently branched from the great mass of granitic rocks (granites, quartz-porphyrries etc.) which is exposed on the eastern flank of the same pass and extended to the environs of the village of Kiura, these rocks being the ore-bringer in this well known tin district.

It is highly probable that the granitic rocks extensively spread below the present surface, though not visible, and also in the environs of the mine, those rocks would be found concealed at no very great depth beneath. The metamorphism of the Palaeozoic sediments in the vicinity of the mine, represented by the recrystallization of limestone into the white saccharoidal variety and the formation of abundant biotite flakes in quartzites which were

metamorphosed from sandstones and slaty sandstones, is due, for the most part, to the contact of eruptive rocks. Moreover, evident pneumatolytic alteration of the country rocks adjacent to the deposit, as will later be discussed, suggests the presence of some igneous intrusion beneath the mine.

Consequently, the ore-bringer of the Mitaté deposit is probably a granitic rock connected with the great batholithic masses⁽²⁾ of this district in a distant way, and on the other hand, joined at a short distance with the smaller masses exposed at Kannegaharu and on the western flank of the pass between Mitaté and Kiura.

The Vein:—

Only one mighty vein has hitherto been found at the Mitaté mine. It is a bedded vein. To say more in detail, it is intercalated between a quartzite and a limestone. The strike of the vein corresponds with the general strike of the Palaeozoic formation of this district, i. e. almost E to W, and it dips northward at a steep angle of 60°—85°. The quartzite forms the hanging-wall and the limestone the foot-wall. The widest portion of the vein is over 10 meters in thickness, though sometimes it pinches to a thickness of 1 meter or less, the average being about 5 meters.

That the deposit in question is a bedded vein but not a bed is shown by a microscopic study of the country rocks lying adjacent to the deposit, as will later be fully discussed under the heading of "Alteration of country rocks." Besides, the following facts suggest the epigenetic nature of the deposit:—1) In the upper part of the deposit, above the second level, it does not always follow the contact of the quartzite with the limestone, but often cuts the quartzite in a typical vein form. 2) In the hanging and foot-walls of the

(2) It is a very remarkable fact that the granitic rocks in this district were very rich in mineralisers. Boron minerals, such as tourmaline, axinite, danburite, datolite etc. are abundantly found at Obira, Kiura and other places, where contact metamorphic ore-deposits and tin veins were formed. Fluorspar is also a frequent associate of those deposits.

deposit, just adjacent to the latter, minute cracks and fissures are developed, being filled with ores of the same character as the main deposit. 3) As observed sometime in the quartzite of the hanging wall, minute cracks in it are encrusted with fine cassiterite prisms.

The upper part of the vein has been under prospect by means of several levels, each with a vertical distance of 30 meters from another, cut eastwards and westwards from the outcrop along a small valley, running S to N or perpendicular to the strike of the strata. The Ōgiri level or the lowermost level, first and second levels (Inchiban-Kōdō and Niban-Kōdō) are important ones at the present time, each being driven over one hundred meters to the east and west directions. At a place far lower than the Ōgiri level, where the vein was measured to be met with at a distance over one hundred meters from the surface, a crosscut was driven through the quartzite (hanging wall) toward the south, this being called "Tsūdō crosscut." At a point of about 15 meters from the entrance of the "Tsūdō," an unexpected deposit was encountered. It is about 3 meters in thickness, and is quite similar in structure and mineralogical composition to the vein under work on the Ōgiri and other levels. The strike and dip of the vein coincide with those of the quartzite.

Fig. 2. Ideal Section through AB.

The crosscut was driven further, and it was found that the foot-wall of the vein was a limestone whose strike and dip also corresponded

with those of the hanging wall quartzite. The crosscut having been driven further in the limestone, the length of it at the present time (April, 1913) is about 30 meters.

It is highly probable that the bedded vein, encountered at the Tsūdō crosscut, is a part of what has been under prospect by means of the levels on its upper portion. The unexpected discovery of the vein by the crosscut, at a much shorter distance from the surface than measured, is explained by the assumption of a normal and strike fault as the ideal profile (Fig. 2.) shows. The presence of the supposed fault may be proved by the further driving of the crosscut as well as more precise geological surveying of the surface of the mountain slope, on which the vein is exposed.

Mineralogical Character of the Vein:—

The vein under consideration is composed essentially of massive pyrrhotite, which is commonly more or less stanniferous as proved by numerous analyses. The low-grade ore, as that containing about 2% tin is so called, is nothing but pyrrhotite with ordinary characters as examined with the unaided eye. As observed under the metallographical microscope with polished specimens, it contains very minute long prismatic crystals of cassiterite imbedded in itself sparingly. The tin content of the pyrrhotite is always due to the sparing mixture of cassiterite.

Often, in the vein of the low-grade tin ore or pyrrhotite, richer parts are found in the form of irregular masses, patches and other possible shapes. The richer portions are never very sharply bounded with the surrounding low-grade ore, but commonly pass over into the latter gradationally. Richer parts containing 5 to 10% Sn are of rather common occurrence, while exceedingly high-grade ores containing more percentage of tin up to 60%, occur only rarely in small masses.

The richer portion, as a whole, is a pyrrhotite mass containing abundant and visible crystals of cassiterite. As examined under

the microscope, in thin sections with transmitted light and in polished fragments with reflected light, the cassiterite is commonly very well crystallized with a prismatic habit and has a size microscopic up to 5 mm in length, being imbedded in a ground mass chiefly composed of massive pyrrhotite with sporadic small irregular masses of chalcopyrite. It is, in thin sections, yellow to brown in colour, and only rarely colorless or violet. In the last case it is strongly pleochroic—light violet $\parallel c$, brown violet $\perp c$. Zonal structure and speckled distribution of colour are very common. It is characterized by high refraction and birefringence, and positive optical character. In some sections, cleavage tracks are not recognized, while in other cases a distinct cleavage parallel to (100) is well observed. Sometimes, characteristic twinning parallel to (101) is developed.

The exceedingly high-grade ore, containing 20 to 60% Sn, is characterized by an adamantine luster due to the predominance of cassiterite. Such an ore is not found everywhere in the vein, but plays a special rôle as an unusual concentration of tin-stone in the richer portions of the vein. This high-grade ore is sometimes represented by a concentration of cassiterite prisms, cemented by pyrrhotite with a small amount of chalcopyrite (Pl. I. Fig. 2). In another case, it is represented by a compact grayish brown mass with a strong adamantine luster. In the latter case, when examined under the microscope in thin sections, it is composed essentially of hypidiomorphic and xenomorphic grains of cassiterite, aggregated firmly (Pl. I. Fig. 4.), though the mineral has a tendency to be long or short prismatic idiomorphic toward the quartz which is composed of angular grains and plays a rôle of mesostasis, filling up the interstices of tin-stones. Sometimes, the cassiterite forms a radial aggregate, composed of stout and slender prisms, so common a structure in tourmaline. In still another case, the high-grade ore is, also showing a dark grayish brown colour and

strong adamantine luster, composed microscopically of abundant idiomorphic cassiterite prisms cemented by chlorite with more or less pyrrhotite, or sometimes by calcite and pyrrhotite (Pl. I. Fig. 3.)

Though the Mitaté vein is composed essentially of pyrrhotite with more or less cassiterite, there are many other minerals, as already mentioned, playing a minor rôle as vein-fillings. They are as follows:—

Quartz. This is an invariable and most abundant associate in common tin veins, but it is found only sparingly in the Mitaté vein. This fact may be regarded as one of the most remarkable characters of the vein in question. Rather rarely it occurs in small masses, intermingled with pyrrhotite or along the selvages of the vein. More or less quartz, though not visible to the naked eye, is always present in the pyrrhotite tin ore, especially in high-grade ores. The quartz in high-grade ores, as shown under the microscope, plays a rôle of mesostasis, filling up, altogether with pyrrhotite, the interstices of cassiterite crystals. It is an aggregate of angular grains, and is sometimes rich in fine slender needles or fibers of an actinolitic amphibole, which is light green to colorless in thin sections.

Calcite. This mineral occurs in small masses also rather sparingly in the vein. It is commonly very coarse-granular and sometimes dark blue in colour. It occurs specially along the selvege of the limestone, and is mingled with pyrrhotite; it represents probably the residuary and recrystallized limestone. In high-grade ores, it is found as microscopic specks filling up interstices of cassiterite crystals and intimately associated with pyrrhotite and quartz. It is, as observed under the microscope with an objective of high power, often full of fine fibers and needles of actinolite, which are scattered irregularly in it, the dark blue colour of the calcite being due to the presence of these inclusions.

Chlorite. This is a mineral occasionally found microscopically,

especially in high-grade ores with a strong adamantine luster. It is commonly almost colorless in thin sections, and is contaminated with very fine opaque dusts, probably of an iron ore. It is characterized by a radial flaky structure showing a cross-bar under the crossed Nicols, and very weak double refraction. It always plays rôle a of mesostasis, filling up, together with pyrrhotite, the interstices of cassiterite.

Arsenopyrite. This mineral occurs usually in small crystals and rarely in irregular masses. It is found only rarely in the important part of the vein, while it increases in quantity gradually toward the upper part of the vein. In the uppermost level at present (several hundred meters above the first level), it occurs more abundantly than pyrrhotite.

Chalcopyrite. This plays the same rôle as pyrrhotite as vein filling, and is evidently of simultaneous deposition with it. It occurs in irregular small masses mingled with pyrrhotite, but never in a large amount nor in large masses.

Zincblende. A black ferriferous variety of zincblende occurs in small masses and patches, but never in crystals, mingled with pyrrhotite. It is peculiar that I could not find any iron pyrite in the vein, so common a mineral in ordinary veins. It might be found, but decidedly not in a conspicuous quantity.

Besides the above mentioned minerals, there occurs occasionally an oxidized ore, called "Boya" by miners and consisting essentially of loose earthy limonite intermixed with clayey substance. The boya is sometimes very rich in tin and is commonly found along the crack of the vein, through which meteoric waters descended and oxidized the sulphide minerals, the tin-stone being unaffected and remaining in intermixture with the limonitic decomposition-product thus formed. The limestone, forming the foot-wall of the vein, is, as common cases are, rich in fissures and caves, formed by the dissolving action of circulating waters. These fissures and

caves, especially those along the selvage of the vein, are often filled with the oxidized ore, which has been transported and deposited by the moving waters percolating through the cracks in the vein.

Alteration of the Country Rocks:—

It has already been stated that the Palaeozoic sedimentaries in this district had undergone more or less contact-metamorphism probably due to the intrusion of granitic rocks, which are exposed in the form of large and small masses, dykes etc. representing parts and branches of a batholith.

Alteration of the rocks just along the Mitaté vein due to the vein forming solutions⁽³⁾ is apparently not very conspicuous. Closer examination, however, reveals many interesting facts, as explained and discussed in the following articles:—

(1) *Formation of new minerals in the quartzite, forming the hanging wall.*

As observed in the hanging wall of the vein at the Tsūdō crosscut, dark and light colored quartzites are sometimes altered to a wollastonite-rock. The alteration zone is never very wide, commonly 1 meter or a little wider from the selvage, and passes into unaltered rocks through gradational forms with more or less lime-silicates. The alteration is naturally most intensive just along the vein, but the wollastonitization seems to have proceeded through fissures and cracks of the quartzite, since the mineral is found frequently in the form of veins and veinlets. Under the microscope, the metasomatic formation of wollastonite at the expence of quartz grains of quartzite is shown obviously, the fibers of the former being developed replacing the latter in every intricate way (Pl. II. Fig. 1). The wollastonite occurs always in aggregates of fibers and prisms often showing a radial structure. Diopside, which is macroscopically light green in colour and always colorless in thin sections, occurs in aggregates of xenomorphic grains, being

(3) "Solutions," in the wider sense.

scattered through wollastonite fibers and quartzite along the vein. It is of simultaneous deposition⁽⁴⁾ with the wollastonite. Frequently, diopside aggregates form netted veinlets with irregular boundaries in the quartzite, indicating that the solution has been blown into the rock through minute cracks and deposited the mineral by a process of metasomatism. Calcite in specks and fine grains is an invariable associate of the wollastonite-diopside mass, sometimes replacing quartz grains in the quartzite too.

Rarely, as observed also at the Tsūdō crosscut, garnet occurs in veinlets in the hanging wall quartzite. A specimen of quartzite, collected there, contains a garnet veinlet with a zone of wollastonite in the middle of it, showing an apparent symmetrical banded structure. Under the microscope, the garnet veinlet, which is macroscopically pinkish in colour, is composed of grains and ill-defined crystals of almost colorless garnet, mingled with more or less calcite and pyrrhotite. Calcite occurs commonly in specks and fills up the interstices of garnet grains and rounded crystals, while pyrrhotite occurs in small masses playing the same rôle as calcite, or rather rarely forms minute veinlets in association with quartz grains, cutting the garnet skarn. A small amount of diopside grains is often mingled with the garnet. The garnet is weakly double-refracting, sometimes showing rather indistinct division of field under the crossed Nicols. This garnet veinlet passes gradually into the quartzite on either side, indicating that the mineral was formed by the metasomatic action of the vein-forming solution. The garnet is sometimes contaminated with innumerable fine needles and fibers of colorless or light green actinolitic amphibole, as can be observed with an objective of high power. The wollastonite occupying the middle zone of the garnet veinlet (Fig.

(4) By simultaneous deposition is meant in this case deposition from the same solution. The diopside, though not well defined in crystal-form, is always of earlier crystallization than wollastonite.

3) and apparently showing a symmetrical arrangement with the garnet zones on both sides, is evidently of later formation than the latter mineral, since microscopic study reveals that the deposition of wollastonite has been performed by a solution which ascended through the reopened cracks in the garnet veinlet⁽⁵⁾ (Pl. II. Fig. 2). The wollastonite veinlet ramifies into minute branches, which

Fig. 3. Garnet vein in quartzite.
a = Wollastonite *b* = Garnet
c = Transitional zone *d* = Quartzite.

run commonly parallel to the selvages of the garnet zone, sometimes cutting the latter very sharply. The wollastonite occurs in aggregates of fibers and prisms usually showing a radial structure. It is always associated with more or less diopside in xenomorphic grains. Calcite is mingled with the wollastonite, commonly in specks and patches, the latter mineral often grading into an intimate mixture of calcite and fine wollastonite fibers. No pyrrhotite speck has been observed in the wollastonite mass, while minute round grains of rutile are sporadically scattered in it.

As observed on the upper levels such as Ōgiri, Ichiban-Kōdō, Niban-Kōdō and others, the hanging wall quartzite has not undergone wollastonitization even along the selvages. More characteristic alteration, however, has been revealed under the microscope, though not conspicuous to the unaided eye. The rock

(5) Common contact-metamorphic deposits, visited by the writer, in which wollastonite and garnet occur together (e.g. Ofuku mine, and many deposits around Mt. Hananoyama in Nagato province, numerous deposits in the environs of Mt. Sannotaké and Yoshiwara mine in Buzen province, etc.), show evidences that the wollastonitization has taken place prior to the garnetization. The deposit in question is by no means a common contact deposit, but a vein formed by an action, comparable with the process by which most contact deposits are formed. It is, therefore, a very peculiar sequence of mineral depositions that wollastonite has been formed subsequently to garnet from the solutions during the same vein forming period.

is sometimes impregnated with pyrrhotite grains and specks or penetrated by minute veinlets and streaks of the same mineral ramified from the main vein. Moreover, it is often coloured very dark green, and contains patches, streaks and veinlets of a mineral with a light violet brown colour, indicating more or less alteration due to the vein-forming solutions. Under the microscope; the quartzite is turbid, being contaminated with fine dusty substances, and impregnated with abundant minute grains of pyrrhotite; the original structure of the rock is rendered obscure owing to the recrystallization of quartz and the formation of new minerals such as albite, chlorite, epidote and others. The following minerals have been identified as newly formed in the quartzite along the vein owing to the infiltration and metasomatic action of the vein-forming solutions, although some of them are products of contact metamorphism, that caused the general alteration of the Palaeozoic sedimentaries in this district, and are not confined to the walls of the vein :—

Quartz. New introduction of some quantities of quartz is evident. The newly formed quartz occurs in patches and veinlets consisting of irregular grains. It is characterized by less turbid appearance than the original quartz of the rock, the latter being mingled and contaminated with kaolinitic matters and sericite scales, probably alteration-products of the feldspathic constituents of the rock. The new quartz, however, contains more or less enclosures, sometimes being full of them. The most characteristic and abundant inclusion is actinolite which occurs in colorless to pale green fine needle-shaped or fibrous microlites, arranged in a confused manner. Fine liquid enclosures are also abundant in this kind of quartz.

Pyrrhotite. This is abundantly scattered in the quartzite near the vein. It occurs usually in irregular grains and rarely in minute tabular crystals showing slender needle-shaped or six-sided sections. In size, it is variable from microscopic up to several millimeters or

much larger in diameter.

Cassiterite. Microscopic impregnation of this mineral in the quartzite just along the vein is sometimes very conspicuous so that the rock is worthy to be worked as tin ore, although richly impregnated parts are hardly discriminative by the naked eye from less disseminated ones. This occurs in grains and crystals. Long or short prismatic simple crystals are common, the characteristic twinning parallel to (101) being sometimes developed. Stellated aggregates of cassiterite needles are of frequent occurrence. It is yellow to brown in colour, and is characterized by high refractive indices and strong double refraction. The mineral, commonly microscopic in size, is scattered through the rock adjacent to the vein, but it is more frequently associated with pyrrhotite grains and newly introduced quartz. In the last mentioned mineral, it is confusedly scattered in grains, prisms and stellated aggregates together with actinolite microlites.

Axinite. This is the most characteristic mineral, newly introduced to the quartzite by the solutions. The light violet brown patches and veinlets in the rock near the vein, are exceedingly rich in axinite crystals as observed under the microscope. The axinite shows a typical wedge-shaped cross-section, and is commonly colorless or sometimes shows a light violet tinge (Pl. II. Fig. 3.) In the latter case it is slightly pleochroic. Extinction and absorption directions indicate clearly that the mineral belongs to the triclinic system. Stronger refractive indices than the adjoining quartz and double refraction of almost the same strength as that, and the optically negative character and biaxiality correspond with the characters of axinite. On qualitative tests, it shows characteristic reactions of boron. The distinct cleavage parallel to (110) is recognizable. In general, the axinite encloses abundant inclusions such as minute grains of cassiterite, chloritic substances, pyrrhotite grains and others. It is commonly associated with

newly generated quartz patches, the latter filling up the interstices of the former.

Epidote. This occurs abundantly in the rock in the form of irregular grains and prismatic crystals. It is commonly very minute in size, the largest crystal observed being a long prism with a length of 0.035 mm. Fine grains of epidote, scattered irregularly in the rock, give a turbid appearance to it under the microscope. This mineral is often found in association with newly formed quartz patches, pyrrhotite grains, chlorite scales etc. It shows various colours in thin sections. Minute grains are mostly colorless, while crystals show a light colour ranging from yellowish to pinkish. Whatever the form and colour may be, it is characterized by high refraction, strong double refraction indicated by the distinguishing bright speckled interference colour. When coloured, it is distinctly pleochroic, yellow to colorless or pink to colorless, the strongest absorption being perpendicular to the principal zone. Owing to the last mentioned character, the colored varieties, especially pink ones, are easily mistaken for tourmaline. But the biaxial character is the conclusive distinction from the latter.

Chlorite and muscovite. The dark green colour of the quartzite near the vein is due to abundantly scattered epidote and chlorite. Chlorite and muscovite are found in the rock in the form of scales and flakes. The former is more abundant and pale green to colorless in thin sections, while the latter is only sparingly found and always colorless. In ordinary light, they appear quite similar, since they show the same forms and cleavage, the only distinguishing character being the strength of double refraction. The chlorite is very weakly double-refracting and shows a grayish interference colour, while the muscovite (partly sericite) shows brighter interference colours. Besides, the former shows a fibrous or flaky radial structure characterized by a cross-bar under the crossed Nicols; the latter not at all. Both the minerals are scattered through the

rock, though the chlorite occurs frequently in association with the newly introduced quartz patches.

Albite. Very minute crystals showing a rhombic cross section—are sometimes abundantly developed in the quartzite, intermingled with the original and recrystallized quartz grains. It is evidently a newly introduced mineral. Examination of the optical properties of the mineral reveals that it belongs to the acidic plagioclase—probably albite. Its refractive indices lower than those of quartz, weaker double refraction than quartz, biaxial nature, and kaolinization by which process the mineral is commonly cloudy are suggestive characters.

(2) *Alteration of the limestone, forming the foot-wall.*

As observed at the Tsūdō crosscut, the limestone, which forms the foot-wall of the vein, is often wollastonitized, just as the hanging wall quartzite. The wollastonite shows a fibrous radiated structure, replacing the limestone in irregular masses or penetrating it in the form of veinlets. Under the microscope, the metasomatic formation of the wollastonite is more evidently recognized than in the case of quartzite. In general, the occurrence of it may be said as exactly the same as in the hanging wall, thus the wollastonitized zone being developed on either side of the main vein. The limestone is metamorphosed to a saccharoidal medium-grained crystalline variety.

In the upper parts of the vein, where the hanging wall quartzite is characterized by the formation of several new minerals, the foot-wall limestone has suffered comparatively little alteration. It is metamorphosed, in general, to a medium-grained crystalline variety with a white, gray or light reddish colour, and is traversed by numerous pyrrhotite veinlets and dark bluish dull-lustered veinlets often forming a net-work. It is peculiar to find that, as examined under the microscope, in the limestone, so easily attackable a rock, none of such minerals as axinite, epidote, tin-stone and others has been developed, while they are often abundantly found

in the hanging wall.

The dark bluish veinlets are the only characteristic mineral aggregates formed in the foot-wall there. Under the microscope, the veinlet is composed of fine fibers and prisms of actinolitic amphibole, with a small amount of dark green chlorite in granules and flakes mingled with more or less muscovite flakes and pyrrhotite grains (Pl. II. Fig. 4). The actinolite is colorless in thin sections, characterized by the perfect cleavage parallel to the longer axis and very slight oblique extinction. The mineral aggregate coincides, therefore, with a dark coloured nephrite both in macroscopical and microscopical characters.

Conclusions:—

We find from the already mentioned facts that the Mitaté vein is a peculiar tin vein in regard to the mineralogical composition and the alteration of the country rocks. As graphically shown by H.G. Ferguson and A.M. Bateman,⁽⁶⁾ pyrrhotite is one of the least frequent associates among the minerals found in numerous famous tin deposits in the world, on the other hand, quartz being the most abundant and frequent mineral. That in the vein now under consideration, pyrrhotite forms the chief vein-filling material, and quartz plays only a subordinate rôle, may be regarded as the most remarkable character of it. Pyrrhotite is believed to be deposited pneumatolytically as well as hydrothermally in deep vein zones.⁽⁷⁾

Another noteworthy fact is that in the vein in question and in the surrounding rocks in immediate contact with it, no fluorine-bearing minerals such as fluorite, topaz, apatite etc. have yet been found. These minerals are so characteristic in tin veins that from the invariable presence of them it is generally concluded that cassiterite is derived from the original granitic magma through the action of the

(6) H.G. Ferguson and A.M. Bateman: *Geologic Features of Tin Deposits*. *Econ. Geol.* Vol. VII, 1912. pp. 230—231.

(7) W. Lindgren: *The Relation of Ore-deposits to Physical Conditions*. *Econ. Geol.* Vol. II, 1907. p. 105 et seq.; H.G. Ferguson and A.M. Bateman: *loc. cit.* p. 230.

“acid extract,” the extraction-process being based chiefly upon a reaction, in the presence of water, of hydrofluoric acid, dissolved in the magma.⁽⁸⁾

Now the question arises as to whether the tin-stone in the case under consideration was deposited by pneumatolysis or not. It is highly probable that the tin was not held in the vein forming solutions in the form of fluoride, as assumed in most cases; the lack of fluorine-bearing minerals⁽⁹⁾ in the vein itself suggests this. On the other hand, the wollastonitization (with simultaneously formed diopside) and garnetization of the hanging and foot-walls, suggest that the vein forming solutions were exceedingly highly heated, the formation of these minerals being commonly due to the metasomatic action of solutions⁽¹⁰⁾ with a temperature far above the critical temperature of water, i. e. pneumatolytic metasomatism.⁽¹¹⁾ The axinite formed in the quartzite adjacent to the vein is, beyond doubt, a pneumatolytic metasomatic product.

Consequently, the formation of the pyrrhotite tin vein of the Mitaté mine is comparable with that of some kinds of contact metamorphic deposit,⁽¹²⁾ which contain no or very small amounts of fluorine or boron-bearing minerals and consist chiefly of wollastonite, diopside, garnet, epidote and others as gangue minerals. The

(8) J.H.L. Vogt: Problems in the Geology of Ore-Deposits. Genesis of Ore Deposits. 1902. p. 646.

(9) They may be found in future, but decidedly not very abundantly.

(10) By the presence of easily volatile components, difficultly volatile components would remain, without crystallizing out, in gaseous solutions with a temperature far below the critical temperature of them. (refer P. Niggli: Die Gase im Magma. Centr-blatt f. Mineral. usw. 1912. p. 321—338.)

(11) Goldschmidt: Die Kontaktmetamorphose im Kristianiagebiet. 1911. pp. 211—226; P. Krusch: Ueber primäre u. sekundäre metasomatische Prozesse auf Erzlagerstätten. Zt. f. prakt. Geol. XVIII, 1910. p. 165 et seq.

(12) e. g. Ofuku deposit (T. Kato: Mineralization in the Contact Metamorphic Deposits of the Ofuku Mine, Prov. Nagato, Japan. Journ. Geol. Soc. Tokyo, Vol. XX, 1913. pp. 13—32). Similar contact deposits accompanying no fluorine or boron-bearing minerals, are found in the vicinity of the Yoshiwara mine, prov. Buzen in Kyushu.

deposit in question is, therefore, a pneumatolytic vein⁽¹³⁾ and it is very probable that it was formed by a highly heated aqueous gas holding in solution⁽¹⁴⁾ Fe, S, Sn, Cu, Si, Ca, B, Zn and other elements. It is also obvious that the fissure along the stratification-plane between the hanging wall quartzite and the foot-wall limestone afforded an adequate passage for the ascension of the solutions, the formation of the fissure being originally due partly to dynamic processes and partly to the contraction of the recrystallized country rocks at the time of contact-metamorphism. That the limestone was attacked metasomatically by the solutions and thus caused the widening of the fissure, is beyond all doubts.

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Explanation of PL. I.

Fig. 1. Black portion of banded quartzite. It is composed of minute grains of quartz with sporadical large oblong grains of the same mineral. It is contaminated with very fine scales of biotite and graphitoid particles, both looking like dusty matters on the photomicrograph. Ordinary light. Magnified 40 diameters.

Fig. 2. High-grade ore, composed of short and long prismatic crystals of cassiterite, the interstices being occupied by pyrrhotite (opaque). White mica (M) is seen, also embedded

(13) This tin vein which is characterized by the association of contact minerals such as garnet, diopside and wollastonite and abundant sulphides, occupies a peculiar systematic position among ore-deposits. It may be regarded as a connecting link between contact metamorphic deposits and common veins. (refer, O. Stutzer: *Kontaktmetamorphe Erzlagerstätten*. Zt. f. pr. Geolog. 1909. p. 154.)

(14) That tin may be held in solution and deposited even under hydrothermal conditions or at atmospheric pressure in the deposits of thermal springs, is generally believed. Refer, W. Lindgren: *Metasomatic Processes in Fissure-Veins*. *Genesis of Ore-Deposits*. 1902. p. 545; H.G. Ferguson etc.: *Loc. cit.* p. 257.

in pyrrhotite. Transmitted ordinary light. Magnified 40 diameters.

Fig. 3. High-grade ore, composed of prismatic crystals of cassiterite, the interstices being filled up by chlorite (C) and pyrrhotite (opaque). Note the inclusions in chlorite. Transmitted ordinary light. Magnified 40 diameters.

Fig. 4. High-grade ore (containing more than 50% Sn), composed of crystals and grains of cassiterite and quartz mesostasis (Q). Transmitted ordinary light. Magnified 40 diameters.

Explanation of PL. II.

Fig. 1. Quartzite (Q) invaded and replaced by wollastonite fibers (W). Ordinary light. Magnified 40 diameters.

Fig. 2. Wollastonite (W) penetrating and replacing garnet-rock (G). The garnet forms veinlets in the hanging wall quartzite. Ordinary light. Magnified 40 diameters.

Fig. 3. Axinite and newly introduced quartz in the hanging wall quartzite. The axinite (A) forms often well defined crystals embedded in quartz (Q). They are associated with microlites of high-refracting cassiterite looking like insect-eggs, pyrrhotite etc. Ordinary light. Magnified 40 diameters.

Fig. 4. Nephrite (N) veinlet penetrating the foot-wall limestone (L). The veinlet is composed chiefly of fine flakes and fibers of high-refracting actinolitic amphibole. Note the comparatively pure state of the recrystallized limestone, which was collected just along the main vein on the Ōgiri level. Ordinary light. Magnified 40 diameters.