JOURNAL OF THE COLLEGE OF SCIENCE, TOKYO IMPERIAL UNIVERSITY.

VOL. XLIII., ART. 5.

A Contribution to the Knowledge of the Cassiterite Veins of Pneumato-Hydatogenetic or Hydrothermal Origin. A Study of the Copper-Tin Veins of the Akénobé District in the Province of Tajima, Japan.

By

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With 7 Plates and 11 Text-figures.

I. INTRODUCTION.

In the course of his investigation of the veins of the Akénobé district, the present writer found many interesting facts concerning the genesis of tin veins in general. Particularly, the writer's attention was called to the presence of chalcedony[1] in the principal vein of this district as an important vein-stuff in association with cassiterite, and to the alterations of the wall-rocks characteristic of hydrothermal processes. Consequently, he was led to the conclusion that the copper-tin veins of this district were formed chiefly under pneumato-hydatogenetic or hydrothermal conditions. These are the same conditions under which the tin veins of the Suzuyama (or Taniyama) mine were formed.[2] It is highly probable that similar

1) T. Katō, "The ring-ore from the Akénobé mine, Province of Tajima, Japan," Journ. Geol. Soc. Tôkyô, Vol. XXIV., 1917, pp. 35–41.

2) T. Katō, "On the pneumato-hydatogenetic or hydrothermal formation of some cassiterite veins. A microscopic study of the tin veins of the Suzuyama mine, Province of Satsuma, Japan," Journ. Geol. Soc. Tôkyô, Vol. XXIII., 1916, pp. 145–164.

tin veins are abundant throughout the world, and they are commonly found in sedimentary rocks more or less distant from igneous rocks or ore-bringers.[1)]

Fig. 1. View of the village of Akénobé, as seen from south.

The Akénobé mining district lies on the upper course of the Akénobé-gawa, a tributary of the Hirotani River, which joins the Maruyama River near the railway station of Yabu on the San'in line. The village of Akénobé (Figs. 1, 4) is situated at the center of the district, about 25 kilometers southwest of the station of Yabu. It is also accessible from the station of Nii on the Bantan line, about 18 km. east from the village. This district has precipitous mountain ranges on three sides, viz., south, east and west, while the Akénobé River runs towards the north and a highway leads from Akénobé to the town of Ôya and beyond along the valley to Yôka and Yabu. It occupies geographically a very disadvantageous position in Eastern Chûgoku.

1) Refer:—H. G. Ferguson and A. M. Bateman, "Geologic features of tin deposits," Econ. Geol., Vol. VII., 1912, pp. 209–262; J. T. Singewald, "Some genetic relations of tin deposits," Econ. Geol., Vol. VII., 1912, pp. 263–279; W. H. Twelvetrees and L. K. Ward, Bull. 8, Department of Mines, Tasmania, 1910.

This district was thoroughly studied and mapped about thirty years ago by T. Kochibe[1], whose report on its geology and ore deposits is of high value even at present, but many new data and facts since brought to light by progressive mining explorations necessitate a more detailed study, which lead to conclusions somewhat different from those reached by the above mentioned author.

Before proceeding further, I must here fulfill the pleasant duty of acknowledging my deep indebtedness to the munificence of Tokujirô Fujita Esq. of Ôsaka, whose liberal offer of all the necessary expenses has enabled me to publish this paper in its present form.

II. TOPOGRAPHY.

The Akénobé mining district forms a part of the mountainous region of Eastern Chûgoku, consisting of precipitous peaks and ranges of about 1000 meters (Fig. 2). The western and central parts of Chûgoku are very remarkable in their physiographic features, inasmuch as they form an elevated peneplain sculptured deeply by rejuvenated rivers (Fig. 3).[2][3] But in the district now in question, the topography is somewhat different. It is in ripe maturity. Peaks are generally more precipitous and higher in this district than in the western and central parts of Chûgoku. The prominent peaks in the area under consideration are Suruga-miné (1053 m.), Takaiwa-miné (1054 m.), Shiroiwa-miné (930 m.) on the eastern side of the Akénobé valley; Sora-yama (977 m.) and Ryōken-zan (786 m.) on the south; and Sajimi-yama (960 m.) and others on the west. On observing the general topography from the summit

1) T. Kochibe. "Geology and ore deposits of the Ikuno mine," 1890 (in Japanese).

2) B. Kotô, "The physiographic type of Chûgoku," Report, Earthq. Invest. Committee, No. 63, pp. 1–15.

3) T. Katō, "The ore deposits in the environs of Hanano-yama, near the town of Ōda, Prov. Nagato, Japan," Journ. Meiji Coll. Techn., Vol. I., No. 1, 1916.

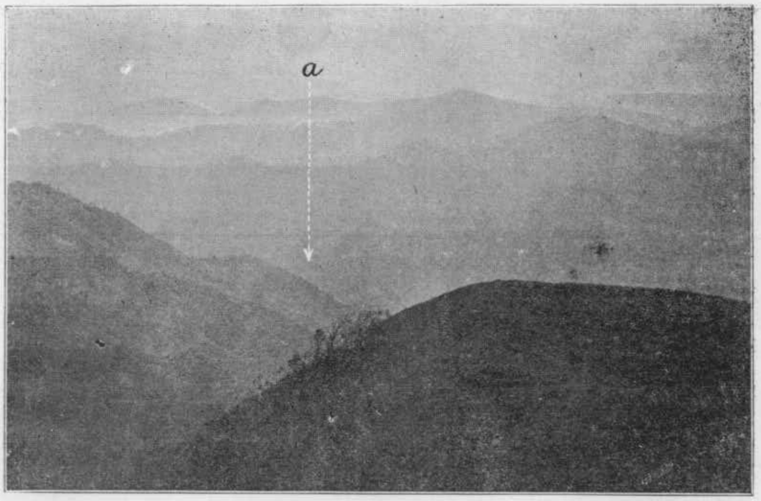

Fig. 2. View of the precipitous mountains and deep valleys in the Akénobé district, as seen from the summit of Suruga miné.
Compare with Fig. 3. a = Akénobé valley.

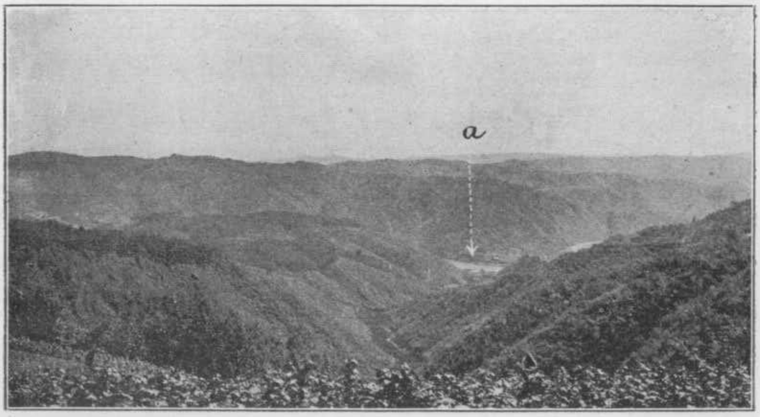

Fig. 3. View of the middle course of the Yoshii-gawa valley, from a height near the Yanabara mine in the province of Mimasaka.
Note the elevated peneplain dissected by rejuvenated rivers, the characteristic topography of the central part of Chûgoku.
a = Yoshii River.

of a high peak in this district, however, we can find here and there rather indistinct relics of the original plateau or elevated peneplain, though the average height is much greater than in the other parts of Chûgoku. It is certain, therefore, that this district underwent peneplanation during the Mesozoic continental period of Chûgoku. During the latest upwarping period, i.e., the Tertiary age, this district was elevated more than 1000 meters, while the upheaval of the western and central parts of Chûgoku has been generally from 400 to 500 meters. Thus the elevated peneplain formed at this period had a higher surface in this district, and, consequently, the rejuvenescence of rivers was more conspicuous and erosion more active here than in the other districts. For these reasons, the district in question is full of precipitous mountains, while the other parts of Chûgoku still remain an elevated peneplain deeply sculptured by rejuvenated rivers. It is proved by field observations, however, that faults and other tectonic disturbances have also played not unimportant parts in the formation of the present physiographic features of this district.

III. General Geology.

In its geological structure Eastern Chôgoku is very complicated, being composed of sedimentary complexes of diverse ages, intricately faulted and folded, and intruded by various igneous rocks. A glance on the general geological map[1] of this region shows this clearly. The Akénobé mining district, being only a small part of this complicated region, encloses comparatively few rock varieties, consequently the intricate major structure cannot be revealed by the field study of such a limited area as the district in question. Considered petrologically, however, this district affords many instructive data, especially concerning the alterations of rocks by hydrothermal solutions, to the action of which the formation of most veins of this district is due.

1) Ikuno Sheet, in scale 1:200,000, published by Imp Geol. Survey of Japan.

This district consists of sedimentary rocks of Paleozoic and Mesozoic ages, together with igneous rocks such as diorites, porphyrites, andesites, liparitic rocks and others.

(A) The Paleozoic Formation.

The Paleozoic formation[1] developed in this district consists chiefly of slaty rocks with subordinate quartzite, sandy rocks, and schalstein in association with diabase. The complex is highly disturbed, but in general the strata strike N. 40°–50° E. and dip towards N.W. at an angle of 30°–50°.

Clay Slate. This forms the most important country rock of the copper-tin veins of this district. Fresh slate, not influenced by mineralizing solutions, is commonly rich in carbonaceous matter and black in colour, hard and compact, and shows rather indistinct cleavage. Under the microscope, the black slate is seen to consist largely of an exceedingly fine textured base or paste, very difficult to resolve, in which fine grains of quartz and feldspar, flakes of chlorite, etc. are imbedded. Carbonaceous matter is abundantly scattered in dusty particles or in minute specks. Sometimes it is silicified to a considerable extent and is penetrated by veinlets consisting of quartz and epidote. This rock is well exposed in the environs of the Shôtoku adit, as well as near the western entrance of the Myôjin tunnel, and in several other places.

The slate is frequently altered to dark green rocks, particularly in the environs of the Daisen vein. At first sight the altered slate is scarcely recognizable, because the slaty cleavage has usually disappeared, and the rock has lost its splintery nature and become rather massive. The faint appearance of bedding in places is the only remaining field evidence of the original character in some of

1) So-called "Chichibu System."

the outcrops. The alteration of the slate into green rocks is most probably due to the action of the mineralizing solutions with which the copper-tin veins are genetically connected, thus affording very instructive data as to the genesis of the veins in question. It will, therefore, be fully discussed in a subsequent chapter.

The slate is sometimes metamorphosed to phyllitic rocks by dynamic processes. These are particularly well developed in the environs of the Minamidani mine. All gradations, from carbonaceous and green slates to highly schistose rocks, are observed. The prevailing rocks are light grayish or light bluish green phyllites, showing a characteristic silky luster, with well developed cleavage structure. As can be observed under the microscope, abundant felty sericite is developed and in places a fair amount of flaky biotite (Pl. II., Fig. 1). Both micas are characteristically arranged along the cleavage planes. The rocks appear to have undergone recrystallization and granulation to a considerable extent, abundant fine grains of feldspar and quartz parallel to the cleavage plane being visible. Veinlets traversing the phyllites are common. Some of the veinlets consist of granular quartz containing a small quantity of epidote grains, while others are composed essentially of yellowish coloured, pleochroic epidote in granular aggregation, in association with a small amount of quartz grains.

A bed of *calcareous biotite-epidote schist* is exposed near the Minamidani mine, which is probably a metamorphosed limestone or calcareous shale. It is intercalated between the phyllites. It is highly schistose in structure and the development both of flakes of biotite and grains and crystals of epidote along the plane of schistosity is very conspicuous. Microscopic crystals of garnet are also developed. As a whole, recrystallized and granulated calcite mingled with a small quantity of quartz grains makes up the main bulk of this schistose rock.

Quartzite. This occurs occasionally in the form of a thick intercalation in the slate complex, forming cliffy walls along its strike, as on the mountain-slope northeast of the Daisen mine (Figs. 4, 5) and in several other places. It is hard and compact, white or grayish white in colour, often stained with limonitic substance and manganese oxide along the cracks and irregular joints in which it is very rich. As can be seen under the microscope, it is composed of inequidimensional grains of quartz, larger grains being scattered like phenocrysts through an aggregate of minute grains (Pl. II., Fig. 6). It is evident that the rock has undergone intense granulation, because the larger grains often show undulatory extinction and their margins grade into cataclastized fine grains. The rock is contaminated with microscopic flecks and stringers of limonite, and is intricately traversed by fine veinlets consisting of quartz grains.

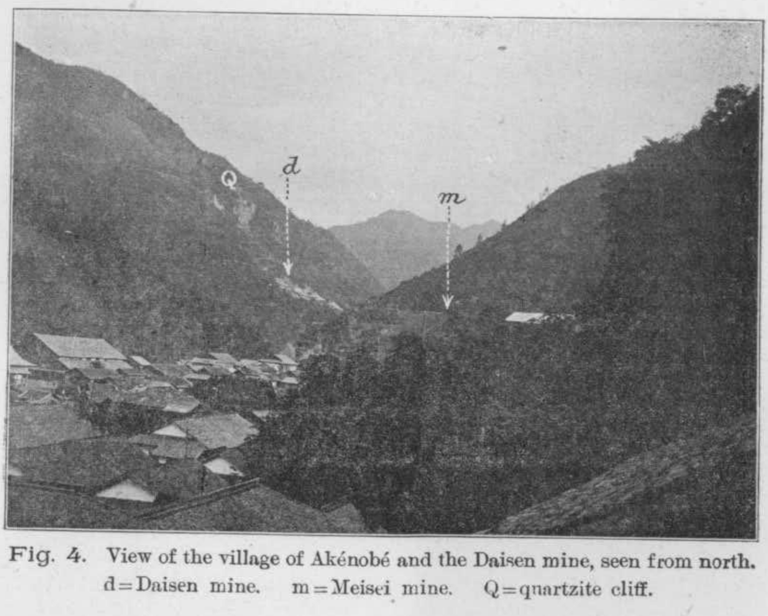

Fig. 4. View of the village of Akénobé and the Daisen mine, seen from north.
d = Daisen mine. m = Meisei mine. Q = quartzite cliff.

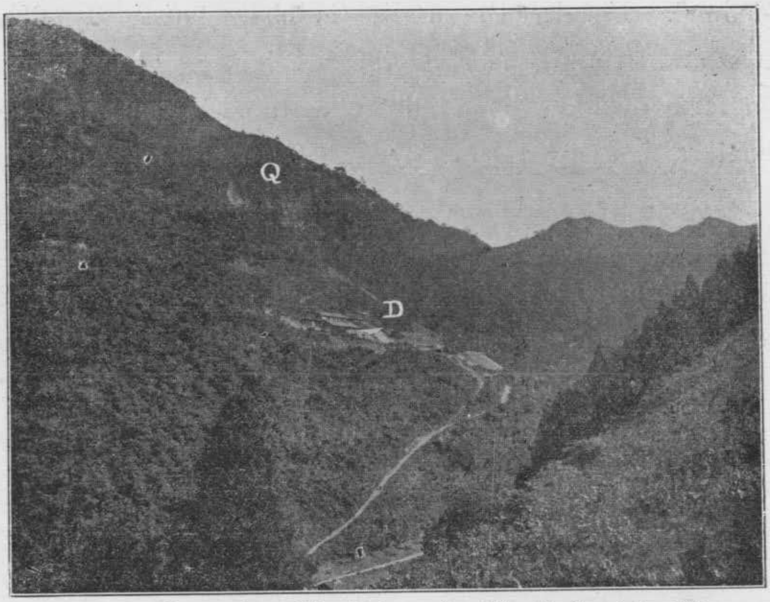

Fig. 5. Nearer view of the Daisen mine (D). Q=Quartzite cliff.

Schalstein and Diabase. Specimens of an aphanitic dark green rock were collected along the road near the Daidô mine. In the field this was taken for a metamorphosed slate, because it was intercalated between highly metamorphosed, more or less epidotized, dark green slates, but after a microscopic examination, it was found to be a diabasic rock, whose original ferromagnesian mineral, augite, is entirely uralitized—uralite diabase. This rock is evidently a member of the Paleozoic formation representing a schalstein horizon, as is usual in the Chichibu System.

Under the microscope, the rock is found to be composed chiefly of amphibole and decomposed plagioclase (Pl. II., Fig. 5); both constituents are 0.3–0.5 mm. in length and confusedly aggregated. Sometimes, however, ophitic and intersertal structures are recognized, the interstices between the lath-shaped plagioclase crystals usually being filled with uralitized augite. Plagioclase is as a rule badly kaolinized and appears cloudy, and the borders are less defined. Usually the uralite is characteristically fibrous in structure and strongly pleochroic, from bright green to yellow. The original form of augite is usually obliterated and has become flaky and bent, although occasionally the transition of the prismatic cleavage from augite to hornblende is observed in basal sections. Iron ores, chiefly of secondary formation, are scattered in fair quantities through the rock. Abundant chlorite, in clusters of minute granules and in large flakes, is developed in some parts.

The rock is occasionally cut by veinlets consisting of xenomorphic grains of fresh albite mingled with chlorite flakes and epidote grains. The epidote is almost colourless in thin section and is characterized by bright speckled interference colours.

Radiolarian Slate. A bed of brownish red slate containing *Radiolaria* remains has been found in the Minamidani area, where the rocks are generally more or less metamorphosed. This is also a characteristic member of the Paleozoic formation of Japan.

(B) The Mesozoic Formation.

In the environs of the Daijukô mine, the country rock consists of black slates interstratified with gray slate, sandstone and conglomerate beds. A lenticular limestone is also found at a spot in the black slate terrane. Thus it differs conspicuously in character from the green slate complex developed in the environs of the Daisen mine.

The black slate complex now under consideration has a general strike of N. 20°–40° E. and dips towards N. W. at an angle of 20°–30°. Thus, the strike and dip of this complex differ very slightly from those of the green slate complex. In this district the two complexes are bounded by a great fault as shown in the annexed geological map (Pl. I.).

As can be observed by a general geological reconnaissance of the Akénobé district, the black slate complex appears to occupy a higher position than the green slate complex, and, moreover, the former is commonly far less metamorphosed and disturbed than the latter. The conglomerate bed, a member of the black slate complex, contains gravels of diverse character, of which flinty hornstone or chert plays an important part; the flinty hornstone is a characteristic member of the Paleozoic formation of Japan. Thus, although the exact age of the black slate complex remains undetermined, because no leading fossil has been found even in the limestone bed intercalated in it, it is evidently younger than the green slate complex and probably of the Mesozoic age.

The predominant rock of the Mesozoic formation in question is black slate. It is highly carbonaceous, and shows distinct cleavage almost parallel to bedding planes. Adjacent to the veins it is frequently more or less silicified or admixed with chlorite, and resembles in some respects the wall-rock of the Daisen and other veins in the Paleozoic terrane. In places, it is intricately traversed by quartz veinlets.

Gray-coloured shale, poor in carbonaceous matter, occurs frequently as a thick bed intercalated between the black slates. Sandy shales, representing all gradations between shale and sandstone, are likewise common associates.

Sandstone is also intercalated between slates, sometimes as a thick bed. When fresh, it is gray in colour and compact in texture, but when altered, particularly by the mineralizing solutions, it has become more or less green in colour and is easily mistaken for a diabase.

A conglomerate bed is exposed on the upper course of the valley along which the Daijukô mine lies. The same bed is extensively developed in this area and is exposed on the road side near the Fudono Pass leading from Fudono to Akénobé. It is several meters thick and contains large and small pebbles of flinty hornstone, clay slate, altered porphyrite and other rocks cemented firmly by a sandy matter. The amount and size of the pebbles vary even in different portions of the same bed, the rock frequently grading into sandstone within a small distance.

A limestone bed is found near the Fudono Pass, a little distant from the road, intercalated between the gray shales and resting directly on the conglomerate bed, just described. It is lenticular in form, with a thickness of several decameters. It is light gray in colour and very compact in texture. No characteristic fossil has yet been found macroscopically as well as microscopically, except sporadic imperfect remains of crinoid stems. The limestone is of very rare occurrence in the so-called Mesozoic formation of this district, and represents local accumulations of calcareous mud in the Mesozoic sea.

(C) Dioritic Rocks.

Dioritic rocks are very extensively exposed in this district. These are all intrusive into the Paleozoic and Mesozoic sedimentaries either in the shape of great masses or in small offshoots. The contact effects are not conspicuous, though the diopsidization of the slate complex, which is observed here and there near the contacts with the dioritic rocks, is obviously related to the intrusion of the igneous rocks under consideration. Other effects, if present, have been rendered obscure by later hydrothermal and dynamic metamorphisms. The diopsidization will be fully treated in a subsequent chapter.

Although all the dioritic rocks in this district belong to the same period of irruption, they show sometimes conspicuous differences in character even in different portions of the same mass. The following are the chief types:—

Gabbroid Diorite. Near the entrance of the Sekiei 5th adit, a small mass of gabbroid rock is exposed. It is a part of the large dyke-shaped mass which is met with in the main cross-cut between the Nihonmatsu and Sekiei veins, and continues to the outcrop of a lighter coloured dioritic rock observed on the slope between the Daisen main adit and the Sekiei 5th adit.

The rock is usually more or less decomposed. It is medium-grained holocrystalline rock, consisting of white feldspathic and dark green ferromagnesian ingredients, sometimes showing indistinct parallel arrangement of the constituent-minerals due to dynamic processes.

Under the microscope, the rock is composed chiefly of plagioclase, hornblende and a small quantity of malacolite (Pl. IV., Fig. 2). The plagioclase is commonly xenomorphic, while the ferromagnesian minerals are idiomorphic or hypidiomorphic. The plagioclase is usually either altered to kaolin, appearing turbid, or changed to dense aggregates of clear transparent flakes and fibers of sericite; sometimes it is altered to saussurite or an aggregate of minute grains and prisms of clinozoisite-epidote minerals. The hornblende forms the predominant constituent of the rock, and occurs in aggregates of hypidiomorphic grains and idiomorphic prismatic crystals, often bent and torn by dynamic processes (Pl. IV., Fig. 5). It is very light coloured but distinctly pleochroic, $\parallel \mathfrak{c}$ light green, $\perp \mathfrak{c}$ light yellow to almost colourless. The extinction angle is very small, $c : \mathfrak{c} =$ ca. 15°. The plagioclase encloses the crystals and grains of hornblende, and fills up the interstices between the latter. A small quantity of colourless malacolite in hypidiomorphic and idiomorphic crystals is found in association with hornblende. Sporadic apatite needles are present as a primary accessory mineral. Insect-egg-like titanite, probably an alteration-product of ilmenite, is widely scattered through the rock. The ferromagnesian minerals are sometimes altered to fibrous chlorite showing an anomalous deep blue interference colour. Moreover, veinlets of chlorite occasionally cut the rock.

Similar rocks are found near the Higashiyama vein, as well as adjacent to the Meisei vein, and in other places.

Altered Diorite. The dyke or elongated boss exposed between the Daisen and Sekiei veins, together with the mass exposed along the road leading from Akénobé to Fudono, belongs to this category.

These rocks are commonly decomposed to dark or light green compact rocks, often showing no granular structure macroscopically. Sometimes they are highly silicified and very hard. In places, they resemble in many respects the green slate which is developed very extensively in this district. When they are found in the green slate terrane, their presence can scarcely be detected without the aid of a microscope.

Under the microscope, plagioclase is altered to kaolin, or more frequently to saussurite or an aggregate of clinozoisite and epidote. Only sporadically is the form of the feldspar preserved, and the characteristic twin-lamellae are observed between crossed nicols. Hornblende is altered to chlorite and its original crystal form is usually obliterated, although very rarely the mineral is found in the form of bent and torn fragments scattered irregularly through the rock. Chlorite often forms veinlets and streaks, occurring either along the boundaries between crystals and grains of the altered feldspar, or cutting them. In the silicified diorite, quartz occurs in intricately intersecting veinlets and in irregular grains filling the interstices between the altered feldspar and other constituents. The quartz shows often undulatory extinction and is cut by stringers of clinozoisite squeezed out from the surrounding saussurite. These facts suggest that the rock has undergone conspicuous dynamic action after the infiltration of quartz.

Schistose Diorite. The diorite in this district shows in places a remarkable schistose structure. The schistose diorite is extensively developed on the ridge between Akénobé and Mikobata, particularly in the environs of the abandoned pits of the Kasei mine. It is evidently a facies of the main diorite from which innumerable offshoots are led out.

As can be observed under the microscope, prismatic crystals of hornblende with no terminal faces are arranged in somewhat parallel orientation, the feldspathic constituents filling the interstices between the hornblende crystals and also forming colourless bands and streaks in alternation with the layers composed of aggregates of prismatic hornblende (Pl. IV., Fig. 6). The feldspar has undergone intense granulation, and is changed to aggregates of fine grains admixed with fair quantities of fibers and flakes of secondary sericite, in association with prismatic crystals and grains of clinozoisite and epidote. The hornblende is light coloured and distinctly pleochroic, light greenish yellow to light green. It shows characteristically corroded forms, embayed by feldspar (Pl. IV., Fig. 6). Pyrrhotite in small specks is widely scattered through the rock. The rock is often cut by quartz veinlets containing a small quantity of flaky muscovite.

Diorite Mylonite. The diorite in this district, especially that forming the main stock which is exposed on the ridge between Akénobé and Mikobata, has undergone intense dynamic processes, resulting in a schistose structure in the rock as described above. The mylonite, now under consideration, is one of the most characteristic products of the dynamic processes.

In the course of driving the Myōjin tunnel which leads from the village of Akénobé to Mikobata, it was found that a more or less altered black slate (Paleozoic) constituted the west entrance of the tunnel and was continuous for about 30 meters, giving place to dioritic rocks, which form the greater part of the mountain mass through which the tunnel was driven. The diorite collected near the contact with the slate is light green and mottled in colour, usually more or less greasy to the touch, and resembling in some respects talcose or serpentinous rocks. Sometimes macroscopic distinction between this rock and the altered green slate showing indistinct bedding planes is very difficult.

Under the microscope, this rock is seen to have been strongly mylonitized. It is composed of irregular-shaped grains of plagioclase and very pale green hornblende. The plagioclase belongs to the oligoclase-andesine group and is characterized by very narrow polysynthetic twin-lamellae, and often shows undulatory extinction. It is usually mylonitized to a considerable extent. The margins of the larger grains are crushed to fine grains (Pl. IV., Fig. 1), and, moreover, fissures and cracks through the larger grains are filled with mylonitized grains. In places, the feldspar is entirely crushed to very fine grains. The hornblende has also undergone mylonitization, though not so intensely as in the feldspar. It is often torn and bent, and in places crushed into minute grains and fibrous flakes commingled with grains of feldspar. The hornblende is occasionally altered to chlorite by later decomposition. Quartz is present in varying quantities, always filling up the interstices between the larger grains of feldspar and hornblende, and also the minute fissures in the rock. It is clearly of secondary infiltration, as the lack of a cataclastic structure suggests.

Akenobeite, a leucocrate differentiated from the diorite magma. At Higashiyama, about 500 meters northeast of the village of Akénobé, a leucocratic rock in the form of a small boss, or apophysis, is exposed in close association with diorite. It lies adjacent to the outcrop of the abandoned copper-tin vein of Higashiyama. In the field it is clear that it represents a leucocrate differentiated from the diorite magma.

The rock in question is medium-grained in texture, the chief component, feldspar, often measuring 3 mm. or more in length. Usually being very poor in ferromagnesian minerals, it is pure white or very light coloured.

Under the microscope, it shows a unique structure. It is composed essentially of thick tabular idiomorphic and hypidiomorphic crystals of feldspar in confused aggregation, the interstices between them being filled with an aggregate of fine grains of quartz (Pl. IV., Figs. 3, 4). Two kinds of feldspar are distinguished, namely, oligoclase and orthoclase. The characteristic narrow polysynthetic twin-lamellae easily distinguish the oligoclase from the orthoclase, which occurs usually in simple crystals or in Karlsbad twins. The plagioclase always exceeds the orthoclase. They are all characterized by the indices of refraction, being lower than the adjoining quartz, and are more or less kaolinized and turbid. The quartz filling the interstices between the feldspars is rather small in amount. Sometimes the feldspars are more or less corroded along their margins, and invaded along the cracks by the quartz. The quartz is easily distinguished from the feldspars by its freshness and positive uniaxial character. Femic constituents play a very subordinate part in this rock. Biotite, characterized by its perfect cleavage and strong pleochroism, wine yellow to dark green, occurs in minute flakes enclosed in feldspars. Sometimes it occurs in hypidiomorphic flakes attached to the well-defined borders of the feldspars, showing its subsequent crystallization. Minute flakes of chlorite, evidently a decomposition-product of biotite, is sparingly scattered through the rock. A small quantity of secondary epidote, very slightly pleochroic, yellow to colourless, and characterized by speckled interference colours, is present in the form of streaky aggregates along the cracks of feldspars, or in irregular patches replacing the same minerals, or in flakes overlapping quartz grains in the cementing matter.

The leucocrate, here considered, shows in places a typical aplitic structure, being fine-grained, rather equigranular, and consisting of rounded grains of quartz and hypidiomorphic and xenomorphic feldspars (both oligoclase and orthoclase) and a fair quantity of green biotite in minute flakes. A gradual transition from one structure to the other may always be observed.

To this peculiar leucocrate, corresponding in mineral-composition to quartz-monzonite-pegmatite or aplite, the writer gives the name of 'akenobeite.' It is the only acid granular rock found in this vein district, and it is particularly noteworthy that it is a differentiation-product of the diorite magma.

All the dioritic rocks in this district, hitherto described, are derived from the same source, and erupted during the same period, probably a late Mesozoic age. The main intrusive mass forms the southern and eastern parts of the Akénobé district, while the offshoots are found here and there in large dykes and bossy masses throughout the vein district. Some of the offshoots are evidently of later intrusion than the main mass, having been derived from the unconsolidated portions of the same magma-basin. It is worthy of special attention that the main stock has undergone intense dynamic processes, resulting, in places, in schistose diorite, mylonite, etc., while the offshoots show frequently only a slight sign of dynamo-metamorphism. The offshoots are often altered to greenstones, particularly near the veins; this alteration is believed to be due to the hydrothermal processes.

(D). Dyke Rocks.

Numerous small dykes, ranging in thickness from a fraction of one meter to several meters, are found in the vein district now under consideration. Those dykes are often decomposed to gray or whitish rocks with an earthy texture. As can be discerned on microscopic study, they are petrologically of diverse characters, the important types being andesites, felsites, porphyries, porphyrites, and diabases.

Hornblende-Hypersthene Andesite. In the abandoned adit of Ishikané, in the Daijukô area, where the eastern continuation of the Daikoku vein was worked, two dykes are found across the vein. They strike N. E. and dip very steeply towards N. W. The one nearer to the entrance of the adit has a thickness of 3 meters or more, the other of only a fraction of one meter. The rock is dark coloured and compact. When decomposed, phenocrysts of feldspar and hornblende are clearly recognizable with the unaided eye, the hornblende occasionally attaining a length of 5 mm. or more, though commonly much shorter.

Under the microscope, the groundmass shows a trachytic structure consisting of innumerable plagioclase laths in parallel or fluidal arrangement, mingled with abundant long prismatic microlites of rhombic pyroxene and fine crystals of magnetite. No glass-base is recognizable; it has probably been devitrified into indistinct double-refracting minerals now admixed with the groundmass. In the groundmass, a small quantity of biotite occurs in irregular microscopic flakes sometimes overlapping the microlites of feldspar and pyroxene. It is characterized by strong pleochroism, perfect cleavage and a nearly uniaxial interference figure under the conoscope.

As phenocrysts occur plagioclase, hornblende and hypersthene. The plagioclase occurs in tabular idiomorphic crystals often attaining a length of 3 mm. It shows broad polysynthetic twin-lamellae. From indices of refraction and extinction angles, it is identified as labradorite. The hornblende is variable in amount and size even in different portions of the same dyke. It ranges from a microscopic size to several millimeters in length, and commonly occurs in well-defined crystals, showing distinct pleochroism, brown to light brown, and small extinction angle, $c:\mathfrak{c}=20°$. The hypersthene occurs in well-defined prismatic crystals characterized by the prismatic cleavage, transverse cracks and straight extinction, and shows distinct pleochroism, $\parallel c$ pale green and $\perp c$ light brownish yellow.

Two-Pyroxene Andesite. This occurs in small dykes, with a thickness varying from a fraction of a meter to 1 meter or more, in the Daisen area. One of this type is found near the entrance of the Kisei main adit, the southern continuation of the Daisen adit, striking N.–S., while another one is found a few hundred meters distant from the same entrance, running N. W. to S. E. obliquely across the Daisen vein (Pl. I.).

The rock is much decomposed and shows an earthy, compact texture with a light grayish colour. Abundant phenocrysts of feldspar with a length up to 1 mm. are visible. Long prismatic crystals of hypersthene, usually less than 2 mm. in length, are sporadically found.

Under the microscope, the groundmass shows a hyalopilitic structure consisting of very minute feldspar laths, often in fluidal arrangement, and a devitrified glass-base mixed with abundant minute specks of calcite, mostly representing a decomposition-product of ferromagnesian minerals (Pl. III., Fig. 4). In fresh specimens a brown glass-base is present, cementing the feldspar laths and contaminated with minute grains of diopsidic augite. Minute crystals and grains of magnetite are scattered through the groundmass. Some ilmenite is evidently present as the presence of leucoxene, developed along the border of a few grains of black opaque iron ore, suggests.

Porphyritic plagioclase is always characterized by polysynthetic twinning and is tabular in habit. Its refraction is far higher than that of Canada balsam. The maximum symmetrical extinction (ca. 35°) shows that it belongs evidently to the soda-calcic group, i.e., the labradorite-bytownite series. While the plagioclase phenocrysts are very abundant, ferromagnesian minerals are very sparse. Only sporadically are hypersthene crystals found with the naked eye. In addition, diopsidic augite, in small prismatic crystals, is sparingly distributed in fresh specimens. This rock, then, may be classed as two-pyroxene andesite very poor in ferromagnesian minerals.

Garnetiferous Felsite-Porphyry. A light-coloured, garnetiferous igneous rock in the form of a dyke is exposed at the stream bottom near the meeting point of the Fudono road and the Mikobata road at the village of Akénobé. It is about 3 meters thick and strikes N. E. A similar garnetiferous dyke was discovered in the underground working in the Ebisu adit in the

Daijukô area. It strikes almost parallel to the vein, i. e., E. to W., and runs along the walls of the vein, cutting it here and there.

The rock is exceedingly altered and bleached. It is white to light greenish white in colour, compact in texture, and contains abundant white phenocrysts of feldspar with a length up to 5 mm. or more. No ferromagnesian minerals are recognizable. Most characteristic is the presence of a fair amount of porphyritic deep red garnet.

Under the microscope, the groundmass shows a microscopic granular structure consisting of fine xenomorphic grains of quartz and feldspar admixed with fair quantities of felty fibers of sericite and specks of calcite (Pl. III., Fig. 3). No ferromagnesian minerals are found in the groundmass; they have been decomposed and have disappeared. Sericite is probably an alteration-product of feldspar, and calcite represents the relics of altered ferromagnesian minerals.

The most important phenocryst is feldspar, ranging from a microscopic size to several millimeters in length. It is abundantly scattered through the groundmass. It is always entirely altered to kaolin which consists of weakly double-refracting powdery grains and gives rise to a turbid appearance. Calcite in irregular specks is also developed in altered feldspar, mingled with kaolin. Whether the feldspar belongs to orthoclase or plagioclase is not determinable, as it is entirely altered. Both kinds have probably been present. That the plagioclase has been present is indicated by the occasional presence of an altered feldspar showing a zonal structure made up of calcite and kaolin layers. Neither ferromagnesian minerals nor their decomposition-products retaining the original forms are recognized as phenocrysts. Irregular flecks of calcite, sometimes admixed with cryptocrystalline hydroxide of iron, are scattered through the rock. The garnet is a very characteristic component and is sometimes abundantly scattered through the rock. It varies from a microscopic size to 3 mm., rarely up to 5 mm., in diameter, and is well crystallized in 2O2. or 202, ∞ 0. It is isotropic and irregularly cracked, and flesh-coloured in thin section. Inclusions of apatite needles, often attaining a length of 1 mm., are very common in garnet. The apatite is found also in the groundmass.

Felsite. A dull-lustered, compact and lithoiditic, white or gray-coloured rock is exposed, as a dyke through the green slates, along the road-cutting between the Meisei and Daidô mines, on the western side of the Akénobé River. It is about 3 meters thick, and strikes N. 20° E. and dips toward N. W. at an angle of 80°.

Under the microscope, it shows a microgranular structure consisting of xenomorphic grains of quartz and feldspar. While quartz remains fresh, feldspar is altered to kaolin admixed with more or less sericite in fibers and scales. No ferromagnesian minerals are recognizable, but here and there are scattered clusters of grains of brown iron ore. No phenocrysts are present.

Felsite-Porphyry. A lithoiditic rock, similar to that described above but evidently with some megascopic phenocrysts of feldspar, occurs in the adit of Mannenkô as a dyke across the vein. It strikes N. 60° E. and dips toward S. E. very steeply. Its thickness is 2 meters or more.

Under the microscope, the groundmass is similar in composition and structure to the felsite described above. It is in places intensely stained with clusters of grains of secondary brown iron ore. Feldspar phenocrysts are usually intensely kaolinized, and sometimes entirely or partially replaced by calcite. Quartz of secondary infiltration is occasionally found as patches and veinlets.

Effusive Liparite. Besides the felsitic rocks in the form of dykes, a liparite as an effusion is extensively developed on the ridge between Akénobé and Mikobata. It covers the dioritic rocks which constitute the main bulk of the mountain under consideration. It is gray or brownish gray in colour, compact in texture, and contains abundant phenocrysts of feldspar and quartz.

Under the microscope, the groundmass consists of light brownish glassy matter contaminated with abundant globulites and margalites, and contains more or less feldspar microlites and minute flakes of biotite. Fluidal structure is not conspicuous. As phenocrysts, quartz, feldspar and biotite are abundant, ranging from a microscopic size to 2 or 3 mm. in length. Quartz occurs as bipyramidal crystals and fragments, and is often magmatically corroded. Feldspar occurs in the form of tabular crystals and also as corroded fragments. Both sanidine and plagioclase are present, but the former is more common. Biotite occurs in hexagonal plates, usually full of magnetite grains.

Porphyrites. Dykes of exceedingly altered porphyrites with macroscopic phenocrysts of feldspar occur here and there in the vein district under consideration. For instance, the dyke exposed across the Higashiyama vein, striking E.–W. and dipping steeply toward S., belongs to this category. It is entirely altered to a gray earthy matter, but still retains a porphyritic structure. A similar porphyrite dyke is found in the underground workings in the Daikoku adit in the Daijukô area, striking N. 30° W. and dipping steeply toward S. W. These rocks are often so altered that they may be crushed to powder between the fingers, and consequently it is impossible to make thin sections.

Near the deposit of the Minamidani mine, a porphyrite is exposed as a dyke through the phyllitic slates. It is extremely altered and has become light brown in colour, but porphyritic feldspar is abundantly recognizable. Under the microscope, the groundmass is composed of lathy crystals and irregular grains of feldspar, mingled with abundant scales and flakes of brownish green chlorite. No glass-base is present; it has probably been entirely devitrified. Minute apatite needles are common as an accessory mineral. Plagioclase as phenocrysts, sometimes attaining a length of 5 mm., is usually exceedingly altered, although the characteristic polysynthetic twin-lamellae are indistinctly recognizable. It is always kaolinized to a considerable extent. Clusters of prisms and ill-defined crystals of clinozoisite and epidote are often developed in the altered plagioclase. Phenocrysts of ferromagnesian minerals are entirely decomposed to greenish brown chlorite with rather irregular outlines, and the identification of the original minerals is hardly possible; occasionally, however, the outlines resembling hornblende crystals are observed.

A dull-lustered green porphyrite is exposed along the highway about 1/2 km. north of the village of Akénobé. It is intrusive in the green slates. As can be seen under the microscope, the rock is extremely altered. The groundmass is difficult to resolve even under high magnification, but it is clearly observed that a secondary feldspathic substance in irregular grains is its chief component, and it is admixed with abundant kaolin and fine fibers and scales of sericite. Apatite needles remain unaltered in the groundmass. The original feldspar phenocrysts are entirely altered to saussurite. Sometimes they are represented by a confused aggregate of grains and prisms of clinozoisite only, and sometimes by an irregular aggregate of grains of newly developed feldspar in intimate mixture with grains and prisms of clinozoisite. Chlorite occurs in irregular flakes, representing probably the relics of the original ferromagnesian minerals. This rock may be classed as saussuriteporphyrite.

Diabase. A dark green rock, called basalt by local miners, occurs as a dyke with a width of about 2 meters, striking N. 60° W. and cutting across the southeastern part of the Daisen vein. It is compact in texture, but is apt to decompose easily into earthy brittle rock when exposed to the air. It is fine-grained and no phenocrysts are recognizable with the naked eye, though sporadically small amygdaloidal cavities filled with calcite and zeolite are observed. Under the microscope, it is generally extremely altered as might be expected, although the original intersertal and ophitic structures are but indistinctly preserved (Pl. III., Fig. 5). Feldspar is entirely altered to kaolin and shows rectangular and long prismatic outlines, being commonly less than 0.5 mm. in length. Ferromagnesian minerals are all altered to chlorite which occurs abundantly in flaky and filmy forms and fills up the interstices between the lathy feldspar crystals. The chlorite is usually contaminated with dusty particles of hematitic iron ore. Sparsely, phenocrysts of feldspar entirely replaced by a zeolite or calcite are found. Minute octahedrons of magnetite are abundantly scattered through the rock. Irregular-shaped cavities as well as the interstices between decomposed feldspar and secondary chlorite are filled with a biaxial zeolite, frequently partially replaced by later infiltrated calcite.

A similar diabase is found in the abandoned adit of Mannenkô as a dyke across the vein.

(E) Faults.

It is not surprising that numerous faults have been encountered in underground workings in this highly disturbed district. In the field, many faults are disclosed by the topography as well as the shifting of the outcrops of rocks and veins. In this district, almost all valleys are fault-valleys. That numerous faults with no surface expression are also present is indicated by the fact that the veins of this district are often exposed in the form of short fragments cut sharply at both ends. The veins themselves commonly represent fissures formed by dislocation, accompanied with slickensides and brecciation, although they are naturally older than the faults cutting them. Some conspicuous faults are shown on the annexed geological map (Pl. I.). Two of the most remarkable, namely, faults the Akénobé fault and the great cross fault of the Daisen vein, are specially considered here.

The Akénobé Fault. This is a N.–S. fault, passing through the village of Akénobé. On the north of the village, it runs along the Akénobé River, while on the south it runs along the flank of the ridge to the west of the Daidô mine (Pl. I.). It seems to dip steeply toward the west. This fault is very significant in this district, because it sharply separates the Paleozoic terrane from the Mesozoic. The foot-wall side of the fault consists of the green slate complex of the Paleozoic age, and the hanging-wall side of the Mosozoic black slate complex. To the north of the village of Akénobé, on the opposite side of Higashiyama, this fault is well disclosed by topographic features. There it is expressed by a valley between the high precipitous ridge consisting of the black slates on the west side and the low isolated mountain consisting of the green slates on the east. This fault is traceable further northwards.

The Cross-Fault of the Daisen Vein. This is the most significant fault for practical purposes in this vein district. It lies to the northeast of the Daisen mine and strikes N. E., consequently all the important veins of the Daisen vein group, striking N. W., are cut at right angles by it (Pl. I.). The fault is utilized for the cross-cut and the main transportation-level connecting the main levels of the Daisen, Nihonmatsu, Sekiei, Hyakken and Shôtoku veins. It is expressed at the surface as a valley and is indicated by the discontinuance of the outcrops of the veins and rocks.

IV. THE VEINS IN GENERAL.

Innumerable veins occur in the district under consideration, and in ancient times, especially in the eras of Daidô (806–809) and Entoku (1489–1491), they were prosperously worked for silver and copper. About thirty years ago this vein district was included in the concession to the Mitsubishi Mining Company. In the early times of prospecting and mining by the present company, the extracted ores were treated as argentiferous copper ore. But recently it was discovered that the siliceous ore containing abundant thin plates of wolframite, sometimes in association with chalcopyrite, contains also much cassiterite in microscopic crystals and grains, and now as much tin ore as copper ore is produced from this district. In fact, the Akénobé mine is the largest tin mine in this country at the present time.[1)]

Veins are occasionally found in the dioritic rocks, but most of them occur in the Paleozoic and Mesozoic terranes, particularly in the green slates. Many veins were once prospected or worked

1) The recent tin production of the Akénobé mine has been :—

1917	377,097 pounds
1918	312,474 „

out. Those now being worked are Daisen, Nihonmatsu, Sekiei, Hyakken, Shôtoku, Daidô, Ebisu, Daikoku and Minamidani. The Daisen vein is the champion lode and produces more tin ore than any other in this district, as well as some quantities of copper ore. Nihonmatsu, Sekiei and Daidô veins also produce tin as well as copper ore. The veins of Hyakken, Shôtoku, Ebisu and Daikoku are worked for copper ore, although a small quantity of tin-stone is commonly contained in them. The Minamidani deposit belongs to a quite different type,[1] and is worked exclusively for copper ore.

The important veins in this district may be divided into three groups according to the strikes, viz., (1) the Daisen vein group or the veins striking N.W.–S.E.; (2) the Daidô vein group or the veins striking N.–S.; (3) the Daijukô vein group or the veins striking E.–W.

The Daisen Vein Group.

The Daisen vein and its parallel companions, namely, Nihonmatsu, Sekiei, Hyakken and Shôtoku veins are most important as ore-producers at the present time. They all strike N. 40°–50° W.

1) The Minamidani deposit lies on the northwestern flank of the peak of Suruga-miné, at a height of about 600 meters above the level of the Akénobé River. It is about 4 km. northeast of the village of Akénobé. It is found in the Paleozoic terrane, but the country rocks are remarkably different from those in the copper-tin vein area. Besides green slates, phyllitic rocks including calcareous phyllite with much epidote, radiolarian slate, etc.—evidently more or less dynamo-metamorphosed slaty rocks, are dominant. They strike N. E. and dip toward N. W at 30°–40°; the general strike and dip thus coincide with those in the copper-tin vein area The deposit is a bedded vein of compact cupriferous pyrite having a lenticular form, 3 meters or more thick in the thickest portion, and contains 4 to 5 per cent of copper on an average Magnetite occurs in admixture with pyrite, and in places it forms black compact masses in place of pyrite. Toward the boundary of the deposit the ore becomes quartzose and grades finally into quartz masses. The deposit is much faulted. Near the deposit under consideration a large porphyrite dyke is found (p. 25).

This belongs to a quite peculiar type of ore deposit, being a dynamically metamorphosed, bedded, epigenetic deposit, evidently different in origin from the copper-tin veins in the Akénobé district, with which the present paper deals. It is noteworthy that a deposit of the same character is met with on the main level driven along the Ôtaké vein, which belongs to the Daisen vein group, the latter cutting the former (p. 33).

and dip very steeply to N. E., and are enclosed in the green slate complex.

The Daisen Vein is exposed on the steep slope of Shiroiwa-daké, on the eastern side of the Akénobé River, and is continuous for more than 600 meters along its strike. Its width varies from a fraction of one meter to 5 meters or more. It is the champion lode in this district and produces tin and copper ores. The structure of the vein is very characteristic and affords instructive data as to the history of the vein formation in this district. It will be fully described and discussed in a subsequent chapter (p. 39).

The Nihonmatsu Vein lies to the north of the Daisen vein. It is a typical copper-tin vein resembling the Daisen vein in structure as well as in many other points, and plays a very important part as a tin ore producer in this district. It is developed for more than 400 meters along the strike, the thickness varying from a fraction of one meter to 3 meters or more. Toward the southern end, the vein ramifies into two branches and becomes poorer in ore-content.

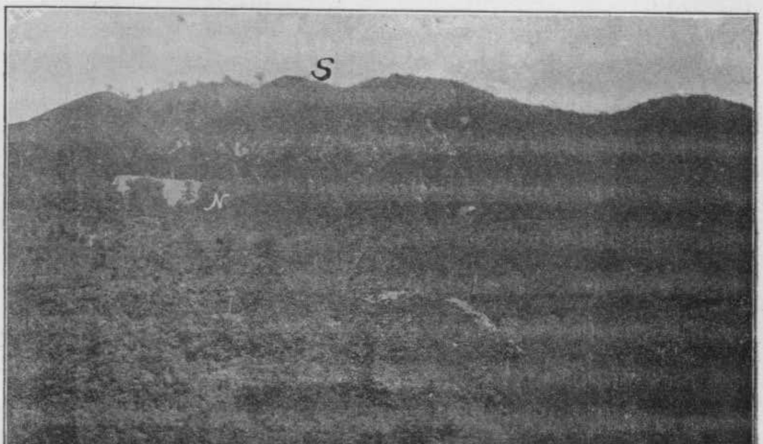

Fig 6. View of Shiroiwa-daké (S), as seen eastward from the Meisei mine.
N = Nihonmatsu mine.

The remaining three veins, Sekiei, Hyakken and Shôtoku, are exposed on the same rugged mountain slope, far above the Daisen vein. They lie at a distance of about 150 meters from one another, and some of them are traceable for more than 300 meters along the strike.

The Sekiei Vein which lies between the Nihonmatsu and Hyakken veins is worked for both copper and tin ores; especially toward the deeper portions it seems to become richer in tin-stone as well as in thin plates of wolframite, thus resembling the Daisen vein in character.

The Hyakken Vein contains rather insignificant quantities of cassiterite and wolframite, and these only in deeper zones, so that at present it is worked exclusively for copper ore. It often shows a symmetrical crustified structure (Fig. 7), consisting of quartz, fluorspar and chalcopyrite. The outermost or first crust consists of quartz with specks of chalcopyrite and bornite, at depths in association with very small quantities of wolframite and cassiterite; the second crust is composed wholly of fluorspar; the third crust is of massive chalcopyrite usually as an irregularly pinching and swelling band; the last crust is composed of barren quartz showing in places a comb structure or a drusy structure with a lining of rock crystals. Occasionally the vein in question produces a ring-ore consisting of concentric layers of quartz and sulphide ores, chiefly chalcopyrite and zincblende. It is very characteristic that the ring-ore found in this vein contains little or no cassiterite, while in the Daisen, Nihonmatsu and Sekiei veins this mineral forms one of the essential components of the ring-ore.

The Shôtoku Vein, though recently opened and only a little prospected, proves to contain almost no tin-stone, and is expected to be worked exclusively for copper ore.

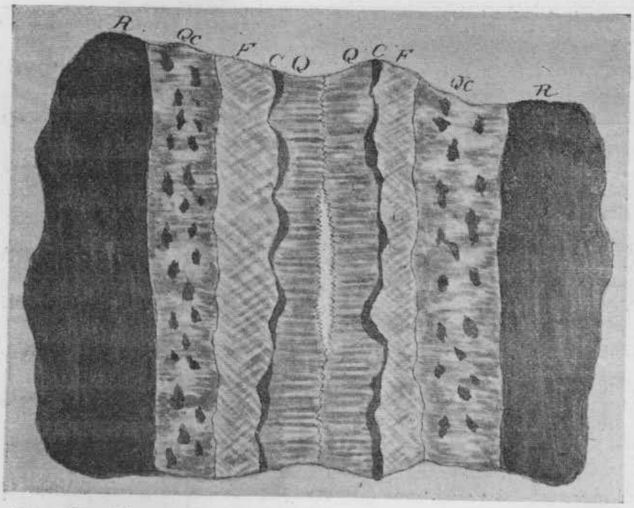

Fig. 7. Diagrammatic sketch of vein piece from Hyakken, showing symmetrical crustified structure.
R, country rock; Qc, quartz with specks of chalcopyrite and bornite, rarely with wolframite plates; F, fluorspar; C, chalcopyrite; Q, quartz.

It is very striking that the above-mentioned parallel veins are diverse in character, in spite of the fact that they are located in a limited area. The tin content is largest in the Daisen vein and decreases gradually toward the northeastern part of the area; the Daisen and Nihonmatsu veins contain much cassiterite and are worked for tin ore as well as copper; the Sekiei vein contains less cassiterite than the above two; the Hyakken vein contains only an insignificant quantity of tin ore and is worked chiefly for copper ore; the Shôtoku vein is believed to contain almost no tin-stone.

Besides the above-mentioned parallel veins, there are a few veins[1] belonging to the same group, or running in the same

1) The Mannen vein, and Kusakané and other veins to the south of the Daisen mine belong also to this group. The Kemuriyama vein, on the southern side of the Akénobé River, just opposite to the Mannen vein, belongs also to this group. It is a copper-tin vein, and rich tin ore was once extracted from it. The Rin'ei and Shiroiwa veins are nothing but faulted and separated blocks of the Daisen vein.

direction, which were once worked or entirely worked out and abandoned, the Ôtaké and Higashiyama veins being most prominent.

The Ôtaké Vein, which runs parallel to the Nihonmatsu vein and about 200 meters distant from it to the northeast, was once worked for copper and tin ores. It is similar to the Nihonmatsu vein in character, and is traceable for about 400 meters along the strike, with a width varying from a fraction of one meter to several meters. In the course of driving the main level, a bedded deposit of cupriferous pyrite, intersected by the copper-tin vein in question, was encountered. The wall-rocks are green slates in association with phyllites striking N. 50° E. and dipping 15°–25° to N. W. This bedded deposit is similar in character to that which is being worked at the Minamidani mine (p. 29). It is lenticular in form, 2 meters or more thick, and is associated with magnetite, especially along the hanging and foot-walls, which are often intensely silicified and grade into massive quartz. The high-grade ore from this deposit contains 7% or more copper.

The Higashiyama Vein, once worked prosperously but now temporarily abandoned, lies in the northern vicinity of the Ôtaké vein. It is exposed for more than 300 meters along the strike, attaining in places a thickness of several meters. It was worked for copper and tin ores as in the Ôtaké vein.

The Daidô Vein Group.

The Daidô vein group lies on the western side of the Akénobé River, just opposite to the Daisen mine. Two chief veins are found there, namely, Uwaban-hi (roof-vein) and Shitaban-hi (floor-vein), both varying in width from a fraction of one meter to 2 meters or more. They generally strike N.–S. and dip eastward very steeply, but they intersect as indicated in Pl. I. They are in places represented by a shattered zone heavily mineralized with chalcopyrite in the form of networks, streaks, patches and impregnation, accompanied by varying amounts of quartz. Sometimes they occur as simple fissure-filling veins showing an irregular massive, or in places banded, structure. Quartz is the principal gangue mineral, and chalcopyrite the chief ore. In the roof-vein, insignificant quantities of wolframite and cassiterite are associated.

Another small vein cutting the two N.–S. veins diagonally, i.e., striking N. E. and dipping northwestward, is found on the northern side of the intersection of the two veins. It is a fault vein, accompanied by conspicuous slickensides, brecciation and shifting of the cut veins, and is richly mineralized with chalcopyrite, especially at the intersections with the preexisting veins.

The above-mentioned veins are worked chiefly for copper ore, but a small quantity of tin ore is also extracted from them.

The Meisei Vein, which lies about 600 meters north of the Daidô mine, belongs to the same category. It strikes N.–S. as in the Daidô veins, but dips westward. In places it is represented by a shattered zone, giving rise to a stockwork deposit, from which very rich tin ore was much extracted, especially from the oxidized zone stained with limonite. At present, this mine is temporarily out of work, but it will be worked again by open-cut in the near future. On the hanging-wall side of the vein, adjacent to it, a fault with the same strike is developed. A gabbroid diorite is exposed along the hanging wall of the fault, being cleanly cut by it.

All veins belonging to the Daidô vein group, such as those of the Daisen group, are enclosed in the green slate complex.

The Daijûkô Vein Group.

The Daiju mine lies about 1 km. southwest of the village of Akénobé. The country rock consists of Mesozoic black carbonaceous slates or shales interstratified with sandstone and others. The shales are in places intensely silicified and chloritized. The general strike and dip of the complex are N. 20°-40° E. and N. W. at 20°-40° respectively, thus being slightly different from those of the green slate complex in the Daisen area.

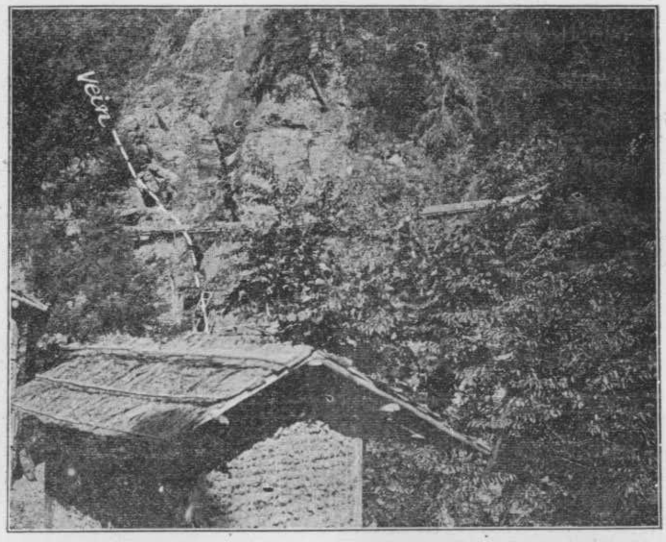

Fig. 8. A view of the Daikoku adit.

There are two main veins in this area, namely, Yebisu and Daikoku, both varying in width from a fraction of one meter to 1 meter or more (Fig. 8). Their strike ranges between E.-W. and N. 60° W. and they dip northward very steeply. These veins are worked chiefly for copper ore, but produce insignificant amounts of thin plates of wolframite and microscopic grains of tin-stone, their mineralogical composition being thus in accord with the Hyakken vein of the Daisen vein group. Moreover, a banded structure showing the same order of mineral depositions as in the Hyakken vein (Fig. 7) is sometimes recognizable in them.

The Fujii Vein, which lies about 700 meters southwest of the Daiju mine on the upper course of the same valley, belongs to the same vein group, striking N. 60° W. and dipping southward very steeply. It is a small vein varying in width up to 1 meter or so, and was once worked for copper ore. It is noteworthy that abundant gelena is associated with chalcopyrite in this vein, while no tin-stone is recognized.

From the foregoing description, it is clear that the veins of the Akénobé district are all consanguineous, and all gradations exist between the copper veins containing little or no cassiterite and the copper-tin veins containing much of the same mineral. The scope of the present paper is to investigate fully the origin of the *copper-tin veins* of this district.

V. The Ore-Bringer.

The ore-bringer for the copper and copper-tin veins of the Akénobé district has long remained problematic.[1] It is generally accepted that tin veins are usually associated with *intrusive* acid igneous rocks such as granites, quartz-porphyries and others,[2] but rarely with *extrusive* acid rocks such as liparites.[3] The associa-

1) In the previous paper ("The Ring-Ore from the Akénobé Mine," loc. cit., p. 36), the writer has suggested that "the veins seem to be related to the liparitic rocks, though not proved," but this has been disproved by later reconnaissances.

2) Summarized by H. G. Ferguson and A. M. Bateman, "Geologic Features of Tin-Deposits," Econ. Geol., Vol. VII., 1912, p. 209 et seq.; J. T. Singewald, jr., "Some Genetic Relations of Tin-Deposits," Econ. Geol., Vol. VII., 1912, pp. 263–279; and R. H. Rastall, "The Genesis of Tungsten Ores," Geol. Magaz., No VIII., 1918, p. 368.

3) Certain tin veins in Mexico are associated with Tertiary rhyolites and rhyolitic tuffs (W. R. Ingalls, "The Tin-Deposits of Durango, Mexico," Trans. Am. I. M. E., Vol. XXV., 1895, pp. 146–163).

A few of the Bolivian tin veins are also related to rhyolites (M. Armas, "Genesis of Bolivian Tin Deposits," Eng. and Min. Journ., Vol. 92, 1911, pp. 311–314.

tion of cassiterite-bearing veins with intermediate rocks is only exceptional.[1] In the Akénobé district no granitic or allied acid plutonic rocks have been observed. Dykes of liparitic rocks are rather scarce, although a liparite flow is extensively developed on the ridge between Akénobé and Mikobata. Dykes of porphyrites and andesites are of commoner occurrence. Those dykes commonly cut the veins intricately, and are clearly later in generation than the latter.

To the writer, the veins of this district seem *to be related to the dioritic rocks*, particularly to the later offshoots from the main diorite magma. As has been fully stated in a previous chapter, of the parallel veins belonging to the Daisen vein group Daisen and Nihonmatsu are most characteristic as copper-tin veins, Hyakken and Sekiei contain only a small quantity of tin-ore, and the easternmost vein, Shôtoku, contains little or no tin-stone. The decreasing tin-ore content toward the east suggests that, the ore-bringer lies nearer to the Daisen vein. The only mighty igneous mass exposed near the Daisen, Nihonmatsu and Sekiei veins is the large dyke-like offshoot of the altered diorite (Pl. I.).

In the Higashiyama area, a leucocratic igneous rock, *akenobeite*, corresponding in composition to quartz-monzonite-pegmatite or aplite,

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1) Many tin veins, once supposed to be connected with intermediate rocks, have been proved to have a close relation to acid rocks. For instance, some Bolivian tin veins were thought by Stelzner to be connected genetically with andesitic rocks (A. W. Stelzner, "Die Silberzinnerzlagerstätten Boliviens," Zt. der deutsch. geol. Gesellsch., Bd. 49, S. 51–142, 1897), but W. R. Rumbald ("The Origin of the Bolivian Tin Deposits," Econ. Geol., Vol. 4, 1909, pp. 321–364) and M. Armas (op. cit.) state that the Bolivian deposits are invariably connected with acid rocks, viz., granitic and liparitic rocks.

The Suzuyama veins in the province of Satsuma, Japan, were supposed to be connected with an andesite, but recently it has been proved that they occur in connection with a granite-porphyry (T. Iki, "Report on the Suzuyama Mine," Bull. No. 46 (in Japanese), Imp. Geol. Survey of Japan, 1914; T. Katō, loc. cit.).

At the present time, most investigators infer that the tin veins are, without exception, genetically connected with acid igneous rocks, i.e., granites, quartz-porphyries, rhyolites and others.

forms a small boss in association with dioritic offshoots, near the chief vein. This rock clearly represents, as already discussed, an acid segregation from the dioritic magma, and it is, in all probability, connected genetically with the adjacent vein.

The Daijukô parallel veins are probably related to the altered diorite mass exposed along the road leading from Akénobé to Fudono.

In conclusion, it seems highly probable that the ore-bearing solutions rose from deeper and at the time unsolidified portions of the magma through the upper solidified portions. It is suggested by the presence of a boss or an apophysis of the leucocrate, akenobeite, that the later solidified portions of the magma were acid in nature and rich in volatile mineralizers due to a process of magmatic differentiation. It is also probable that in the future more offshoots of diorite and acid differentiation-products will be discovered in this district by underground explorations.

VI. THE COPPER-TIN VEINS.

Under this heading the writer confines himself to the structure, character of mineralization, and alteration of the wall-rocks of the Daisen vein, of which more complete observation and more careful study of thin sections have been made than of any others. As a matter of fact, the Daisen vein is worthy to be taken as representative of the copper-tin veins of this district, since it is the most productive vein and other veins now being worked or once worked, such as the Nihonmatsu, Sekiei, Ôtaké, Kemuriyama, etc., show a strikings imilarity to it. Consequently, the conclusions derived from the Daisen vein apply to the remainder of the similar veins in this district.

The vein is composite in structure. It represents a shattered zone filled with ores, gangue minerals, and fragments of partially or entirely altered country rock, and the filled fissures have been repeatedly reopened and recemented by successive mineralizations (Fig. 9). In some places, however, the structure of the vein is very irregularly massive and brecciated.

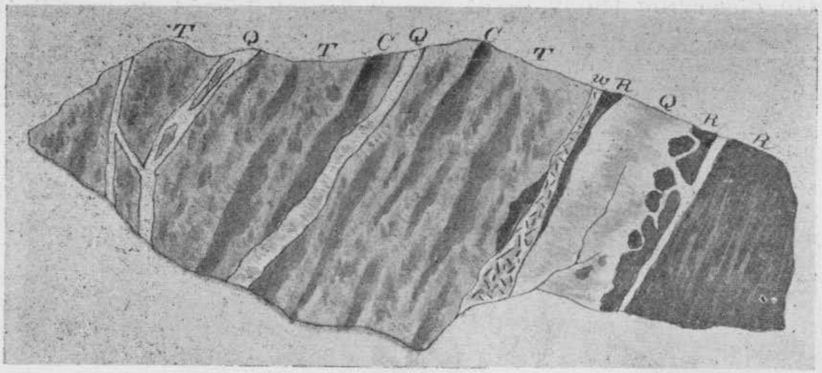

Fig. 9. Diagrammatic sketch of a vein-piece from Daisen. About 1/5 natural size. R, country rock; T, cassiterite ore of the first stage of mineralization, with specks and streaks of chalcopyrite, etc.; *w*, quartzose wolframite-cassiterite ore of the second stage of mineralization; C, chalcopyrite veins and veinlets of the third stage of mineralization; Q, milky quartz with a little chalcopyrite (fifth stage of mineralization). Zincblende veinlets of the fourth stage of mineralization are not represented here.

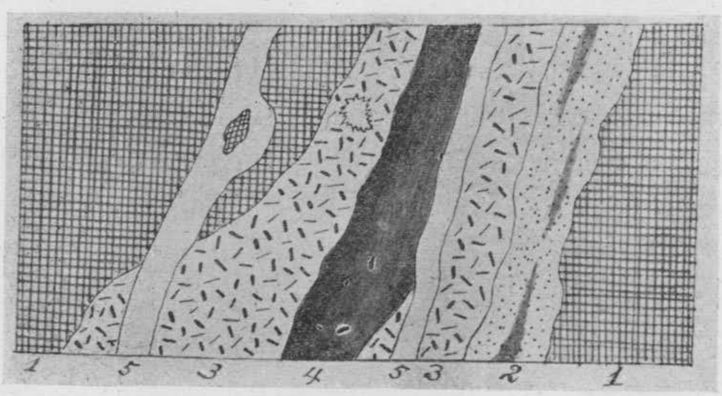

Fig. 10. Diagrammatic sketch of the exposure at a working place in the northern part of the Daisen vein (Kominé).
1, country rock; 2, copper-tin ore; 3, wolframite-bearing tin ore; 4, copper ore; 5, barren quartz.

The composite nature of the vein and evidence of re-opening of the fissures are well observed at many working places. The diagrammatic sketch of a vein-specimen from a working place in the northwestern part of the Daisen vein, shown in Fig. 9, and that of the exposure at another working place of the same vein shown in Fig. 10 illustrate its composite nature very well.

On observing the vein at the working places and examining the vein-specimens in the laboratory, we can recognize five successive stages of mineralization in the history of the formation of the vein under consideration, viz., (1) deposition of the main cassiterite ore, (2) deposition of wolframite-cassiterite ore, (3) deposition of chalcopyrite, (4) deposition of zincblende, (5) deposition of barren quartz, with a little chalcopyrite.

(1) The Deposition of the Main Cassiterite Ore.

After the formation of the vein fissures and the brecciation of the wall-rocks along them, the main mineralization took place. By the action of the mineralizing solutions which ascended through the fissures, the wall-rocks as well as the blocks and fragments of the country rock filling the fissures underwent conspicuous alterations, chiefly silicification. The solutions at this first stage of mineralization were very siliceous. The rock-fragments in the vein occasionally show intense sideritization instead of silicification, being partially or entirely converted to granular aggregates of siderite.

The product of this stage is the main cassiterite ore consisting chiefly of quartz with abundant cassiterite. The cassiterite is very minute in size, ranging from a microscopic size up to 1 mm. in length, and is irregularly scattered in quartz in the form of grains and ill-defined short prismatic crystals.

The high-grade ore of this stage is a quartzose ore containing abundant cassiterite in clusters, and has a dark gray or dark brown colour. Under the microscope, the cassiterite is always the earliest crystallized mineral and is enclosed in irregular grains or hypidiomorphic crystals of quartz.

The main cassiterite ore is sometimes represented by a *ring-ore*,[1] which is especially well developed in certain parts of the Daisen vein. The ring-ore is formed in places where fragments of the country rock abound. It is composed of layers of quartz and cassiterite deposited successively along the altered rock-fragment, thus giving rise to an aggregate of concentric banded rings (Pl. V., Figs. 2, 3). As can be observed macroscopically and microscopically, the rock-fragments forming the nuclei of the rings are extremely silicified and sometimes almost entirely altered to an aggregate of minute quartz grains, but they are rarely partially or entirely sideritized.

The first crust formed on the fragments consists of quartz and cassiterite; microscopic grains and crystals of cassiterite forming a concentric streak (Pl. V., Fig. 2) are enclosed in the quartz crust. Sporadically, the rock-fragments are directly surrounded by the cassiterite band which is encrusted with a quartz layer; this is a special case and under the microscope a certain amount of quartz is always found mingled with cassiterite. The second crust is very characteristic. It is composed of *chalcedony*. On keen observation, we can recognize a concentric layer with a thickness of 3–5 mm., covering the first quartz-cassiterite layer, and having a luster resembling wax, with a pale blue colour (Pl. V., Fig. 2). Under the microscope, it is essentially a fibrous aggregate showing a radial and concentric structure (Pl. VI., Figs. 1, 2, 3). The fiber shows

1) T. Katō, "The ring-ore from the Akénobé mine," loc. cit.

an optically negative character along the longer zone, the greatest elasticity-axis existing along the longer axis. Refraction is always a little higher than that of Canada balsam. It is SiO_2 in chemical composition. These properties correspond exactly with those of chalcedony. The third crust is represented again by a quartz layer, which is the last zonal precipitation in the stage of ring-ore formation. Occasionally, if not always, a second cassiterite-bearing band, macroscopically an insignificant dark streak, is developed concentrically in the last quartz crust (Pl. V., Fig. 2). Rarely, however, is this band represented by a thick cassiterite layer, in which case the ring-ore contains two concentric cassiterite layers. This quartz zone is characterized by numerous small drusy cavities lined with small crystals of quartz, which are sometimes encrusted with fine crystals (cubes) of colourless or light purple fluorspar, pyramidal crystals of light brown scheelite, and minute crystals of siderite.

Zincblende sometimes plays an important rôle in the formation of the ring-ore. Exceedingly silicified rock-fragments are occasionally encrusted with a zincblende layer, a few millimeters thick, and subsequently covered successively by the quartz-cassiterite, chalcedony and other layers. In places the nucleus of the ring-ore has been heavily impregnated with, or entirely replaced by, zincblende. Chalcopyrite and bornite play also a significant part in the ring-ore. They occur as an admixture in the cassiterite-bearing crust commonly in the form of small specks, or sometimes are deposited directly on the nuclear rock-fragment. Frequently they are scattered in the form of minute grains and streaks through the silicified rock-fragment. It is certain that at an early epoch of the ring-ore formation small quantities of zincblende, chalcopyrite and bornite have been deposited from the vein-forming solutions, the cupriferous sulphides being evidently of later deposition than zincblende. Pyrrhotite occurs also as an early precipitation in this stage, sometimes enveloping cassiterite.

The ring-structure in the ore of the first stage of mineralization is often obliterated and rendered obscure by later impregnation of chalcopyrite and other sulphides of the third stage of mineralization. The ore of this stage, showing no ring-structure and consisting of massive quartz with abundant cassiterite, is not infrequently cut by innumerable veinlets and streaks of chalcopyrite, and is heavily impregnated with the same mineral belonging to the third stage of mineralization, giving rise to a massive siliceous chalcopyrite-cassiterite ore (Fig. 9).

Toward the end of this stage, small quantities of siderite, fluorspar, scheelite, and again some sulphides such as pyrite and chalcopyrite were precipitated. It has already been stated that in the ring-ore, siderite, fluorspar and scheelite occur as linings of the drusy cavities. Moreover, siderite in irregular specks occurs as a filling of the interstices between quartz grains. Pyrite and chalcopyrite occurring as impregnation in quartz in close association with siderite belong also to this stage.

The products of the first stage of mineralization, particularly the chalcedony[1] in the ring-ore, afford very instructive data as to the genesis of the Akénobé veins. Though the temperature limits in which chalcedony is formed are not yet experimentally determined, it is certain that this mineral has never been found in pneumatolytic deposits characterized by high temperature gangue minerals. J. Königberger and W. J. Müller[2] observed that gelati-

1) It was told by a mining engineer that in a part of the Daisen vein a similar chalcedony was once found as crustified layers along the selvages. But such an occurrence is of extreme rarity.

2) Königberger und Müller, "Versuch über die Bildung von Quarz und Silikaten," Centrbl. f. Mineralogie usw., 1906, S. 371.

nous silica was deposited at 360° C., but they believe that at this temperature the material is unstable and would soon be converted to quartz. This is the highest temperature at which the gelatinous silica has been synthesized.

The work of Hein, Leitmeyer and others[1] leads to the conclusion that chalcedony is in all cases composed of quartz fibers and that it always results from the crystallization of gelatinous silica either soon after the deposition or at a later time, and that gelatinous silica may in becoming crystalline either turn into granular quartz or into fibrous quartz, i.e., chalcedony.

In the case of the ring-ore now in question, it is evident that the crust of chalcedony represents a gelatinous silica transformed to fibrous quartz as its opaline appearance and globular habit under the microscope clearly suggest (Pl. VI., Figs. 1, 3). Consequently, it is highly probable that the copper-tin veins of the Akénobé district were formed chiefly under pneumato-hydatogenetic or hydrothermal conditions, below the critical temperature of water (364° C).

It is noteworthy that in the Nihonmatsu and Sekiei veins, though a similar ring-ore occurs very commonly, no typical chalcedony has yet been observed. But under the microscope, the quartz crust corresponding to the chalcedony crust of the Daisen ring-ore is revealed to be an aggregate of indistinct broad fibers, probably representing an advanced stage of transformation of opal to quartz.[2]

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1) Summarized in Doelter's "Handbuch der Mineralchemie," Bd. 2, pp. 165–190, 240–264 (1914).

2) Many examples of transformation of opal to chalcedony and quartz were enumerated by F. Cornu and Leitmeyer ("Über analoge Beziehungen zwischen den Mineralien der Opal-, Chalcedon-, der Stilpnosiderit-, Hämatit- und Psilomelanreihe") in Zeitschr. f. Chemie u. Industrie der Kolloide (Kolloid-Zeitschrift), Bd. IV., 1909, S. 285–290.

(2) The Deposition of the Quartzose Wolframite-Cassiterite Ore.

A quartzose ore containing abundant wolframite and cassiterite occurs in the form of a vein cutting the composite vein longitudinally, its width varying from a few centimeters to one meter or more. It is most typically developed in the Daisen vein. This ore is the product of the second stage of mineralization, and cuts the cassiterite-quartz ore, including the ring-ore, of the previous stage, often showing well-defined boundaries (Fig. 9). The writer observed at a working place of the Daisen mine a section of the vein which showed the ring-ore of the first stage in contact with the wolframite-cassiterite ore of the second stage. The contact was sharply defined, suggesting that the latter was deposited later along a reopened fissure cutting the former.

The ore in question is practically the same in appearance as the product of the previous stage, except that it contains innumerable thin plates of wolframite (Pl. V., Fig. 1). Wolframite is characteristically paper-like, commonly with a thickness of less than 0.5 mm.; and confusedly scattered black streaks, representing cross-sections of the wolframite plates, are observed on the fracture-surface of the ore. Along the walls of drusy cavities of the ore of this stage, small but beautiful crystals of fluorspar and scheelite are often found.

In places, specks and patches of native bismuth are found in this ore. This mineral is of rare occurrence in the vein under consideration, and occurs exclusively as a product of the second stage of mineralization. Sometimes, it is found in the form of streaks filling up the cracks along the thin plates of wolframite. Still more rarely, bismuthinite is found embedded in quartz. It is often intimately associated with native bismuth, the latter being enclosed in the former with very irregular boundaries. Chalcopyrite in minute specks is usually intimately admixed with bismuthinite. It is indicated by their modes of occurrence that native bismuth deposited first and that it had later undergone sulphuration which has advanced gradually toward the interior. Fluorspar in small masses is sometimes found in the ore under consideration.

On examining this ore under the microscope, the wolframite shows a long needle-shaped cross-section (Pl. VII., Fig. 5) embedded in an aggregate of quartz grains. This mineral is the earliest to crystallize out. It is sometimes altered to a colourless, transparent, strongly double-refracting mineral—probably scheelite, the alteration-product assuming the original platy crystal often in admixture with remnants of wolframite (Pl. VII., Fig. 5). Cassiterite is the next crystallized mineral. It is usually embedded and enclosed in quartz grains in the form of small crystals and grains. It is a noteworthy fact that minute crystals and grains of cassiterite show a tendency to accumulate along the thin plates of wolframite; in thin sections it is observed that the cassiterite grains and crystals are attached to the slender needle of wolframite like magnetic sands attracted by a magnet. Quartz is mostly of subsequent crystallization to wolframite and cassiterite, and occurs as aggregates of grains enclosing them. But in places well-defined hexagonal prisms of quartz are developed surrounded by grains of the same mineral often showing a zonal structure due to successive growths, and zonally arranged inclusions of fine crystals and grains of cassiterite and others (Pl. VII., Fig. 1). Fluid inclusions are abundant in quartz.

Occasionally a ring-ore similar to that of the first stage of mineralization is found as a product of this stage. The present writer found a typical one of this category in the Sekiei vein, in which two or three cassiterite-bearing layers are usually present in alternation with quartz crusts. The most characteristic arrangement of the layers in the ring-ore in question, as observed in thin sections, is shown in Fig. 11. The first crust is composed of hypidiomorphic crystals of cassiterite which are frozen to the silicified rock-fragment; the second crust is composed of quartz grains containing sporadic cassiterite crystals; the third crust is made up again of cassiterite crystals; the fourth one consists of large grains of quartz, on the outside of which a broad crust consisting of wolframite plates, cassiterite crystals and quartz grains is developed. In places, these cassiterite-bearing bands unite together and form a wolframite-cassiterite-bearing layer, which is deposited directly on the rock-fragment. The quartz layer containing wolframite and cassiterite frequently shows indistinct radial fibrous or radial bladed structure, representing probably an advanced stage of transformation of opaline silica to quartz.

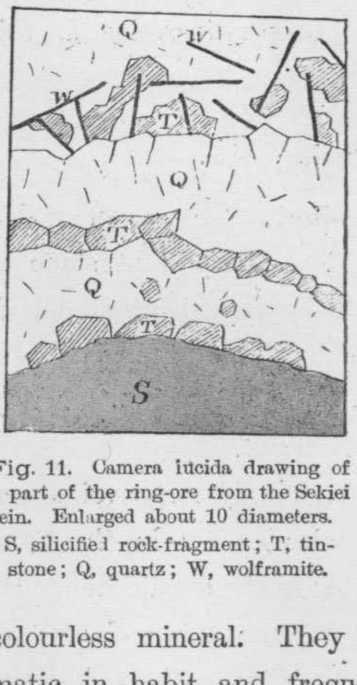

Fig. 11. Camera lucida drawing of a part of the ring-ore from the Sekiei vein. Enlarged about 10 diameters. S, silicified rock-fragment; T, tinstone; Q, quartz; W, wolframite.

Microscopic topaz in the Daisen vein. The writer found, in the course of microscopic examination of many thin sections of the quartzose wolframite-cassiterite ore from the Daisen vein, several microscopic crystals of a colourless mineral. They are embedded in quartz, usually prismatic in habit and frequently showing terminal faces (Pl. VII., Fig. 2). The size ranges from 0.15 to 0.5 mm. in length, no macroscopic crystals having yet been found.

The mineral shows straight extinction and fairly high refringence, much higher than that of the enclosing quartz; consequently its border appears dark and sharply defined. Double refraction is weak, about the same as, or a little weaker than, in quartz. The basal cleavage is well developed. The character of double refraction along the principal axis is negative. Under the conoscope, a biaxial interference figure appears, and it has been determined by means of the gypsum plate that the mineral is optically positive. The basal section is typically rhombic in shape. These properties coincide exactly with those of topaz.

The occurrence of the microscopic crystals of topaz in the ore in question is not surprising, because it is suggested by the presence of fluorspar that fluorine-mineralizers have played an important part in the formation of the copper-tin veins of this district.

(3) The Deposition of Chalcopyrite.

The deposition of the wolframite-cassiterite ore was succeeded by the deposition of chalcopyrite. This is an important stage of metallization in the vein district now under consideration, but it must be borne in mind that the deposition of chalcopyrite and bornite took place also in the first stage of mineralization, as already stated, although the quantities were insignificant.

The chalcopyrite of this stage forms not only large veins and patches through the composite vein, but also occurs in the form of streaks, stringers and flecks impregnated in the cassiterite-quartz and quartzose walframite-cassiterite ores. It surrounds and embays all earlier minerals, and fills the interstices between the wolframite plates.

Owing to impregnation with chalcopyrite, the treatment of the tin ores is often rendered very difficult. Thus very rich copper ores containing a small quantity of cassiterite are extracted from some working parts of the vein, while high-grade tin ores containing more or less chalcopyrite are also being mined at other places of the same vein.

(4) The Deposition of Zincblende.

Occasionally veinlets of zincblende with a width varying from a few millimeters to several centimeters are found in the composite vein. They cut through massive chalcopyrite ores, often passing into ramifying stringers. The veinlet consists mainly of granular massive zincblende admixed with varying amounts of quartz. Very small quantities of galena, chalcopyrite and secondary bornite in minute specks are associated with it.

The product of this stage must be distinguished from similar ones of the earlier stages, because zincblende was deposited to a less extent, as already stated, in the first stage of mineralization in association with the cassiterite-bearing ring-ore, and in others.

(5) The Deposition of Barren Quartz.

Veins and veinlets of quartz representing the last mineralization are found everywhere in the veins of the Akénobé district. They vary in thickness from a few millimeters to several decimeters and cut the products of all earlier stages, filling the reopened fissures in the composite veins, and either running parallel to the selvages or irregularly across them (Fig. 9). They consist of massive, milky or transparent quartz, and are rich in drusy cavities lined with slender crystals of quartz. A very small quantity of chalcopyrite in the form of small masses and specks occurs sporadically in the veins under consideration; it belongs to the same stage of mineralization as the associated quartz. Considered from an economic point of view, the quartz veins of this stage are not important.

VII. The Alteration of the Clay Slate.

As already stated, the slate complex, particularly of the Paleozoic formation, has been subjected to intense alteration. The metamorphism of the complex by dynamic processes has been fully treated under the heading of general geology. In this chapter the alterations other than dynamo-metamorphism are dealt with, which are connected directly or indirectly with the formation of the copper-tin veins of this district.

(A) Diopsidization of the slate.

Along some contacts with the dioritic rocks the slate is metamorphosed into light green rocks, occasionally showing intricately contorted, alternating bands consisting of light green compact and deep green granular layers. The deep green granular layer represents an injection of diorite along the bedding-plane, and is composed of crystals and grains of green hornblende with more or less feldspar, while the light green band is composed of silicified slate mingled with abundant patches and streaks consisting of minute short prismatic crystals and grains of colourless diopside. Minute grains of diopside are also scattered through the whole silicified layer (Pl. III., Fig. 2). This layer may properly be called a diopside-hornfels, and is one of the typical products of contact-metamorphism. Alteration of this kind is well observed along the road side between Akénobé and the Fudono pass.

(B) Chloritization of the slate.

The slaty rocks adjacent to the copper-tin veins are usually altered to dark green rocks. The green slate is not confined to the walls of the veins but covers a considerable area in this vein district. It is particularly well developed in the Daisen area. When the bedding-plane and slaty structure are indistinct, it is easily mistaken for altered diorite which occurs in large dykes or small bosses here and there in the terrane of the green slate complex.

Under the microscope, flakes and fibrous flecks of chlorite are abundantly scattered through a clayey ground, sometimes being arranged along the cleavage-plane, intricately mixed with dusty carbonaceous matter. Frequently, the chloritized rock is represented by sericite-chlorite slate which is made up largely of sericite fibers, minute flakes of chlorite and more or less infiltrated quartz grains —a characteristic hydrothermally altered slate.

The chloritized slate, as well as the chlorite-sericite slate, is in places irregularly traversed by microscopic quartz veinlets which pass gradually into highly silicified rock-portions (Pl. II., Fig. 4). It is thus suggested that the main chloritization of the country rock took place prior to the main silicification.[1] That the chloritization of the slate is intimately related to the vein-formation is indicated by the fact that the alteration is most intense in the area rich in veins.

(C) Silicification of the slate.

The slate adjacent to the veins is often intensely silicified, resulting in a hard quartzose rock usually mottled with light brownish and greenish colours. The silicified slate is commonly cut by netted veinlets of a reddish brown colour.

1) A subordinate silicification had taken place prior to the main chloritization, the slate being in places altered to an aggregate of fine quartz grains, which are overlapped by later infiltrated chlorite flakes.

Under the microscope, the rock is found to be almost entirely composed of fine anhedral grains of quartz, and shows a quartzitic structure, penetrated irregularly by microscopic veinlets consisting of somewhat larger grains of quartz (Pl. II., Fig. 3).

The reddish brown veinlets cutting the silicified slate are revealed, under the microscope, to consist of siderite and limonite, the latter mineral being an alteration-product of the former. It is evident, therefore, that the silicification took place prior to sideritization. This will be fully considered in a subsequent article.

(D) Epidotization of the slate.

In certain places in this district, the clay-slate is intensely epidotized. This alteration is best observed in the environs of the Mannen adit and near the western entrance of the Myôjin tunnel, in the southern part of the vein district under consideration. There, the black slate is intricately penetrated by netted veins and veinlets and irregular patches of bright green epidote, occasionally in association with brick-red patches, thus giving rise to a confusedly mottled appearance of black, green and red colours.

The bright green patches and veinlets are composed of epidote, chlorite and quartz, as is revealed under the microscope. Epidote occurs in hypidiomorphic grains and idiomorphic prisms, and shows distinct pleochroism, bright green to light yellow, and bright speckled interference colours (Pl. II., Fig. 2). Quartz occurs in xenomorphic grains and encloses epidote, slightly pleochroic green chlorite in the form of flakes sometimes occurring in place of quartz.

The brick-red patches are composed of quartz full of hematite dust, which is sometimes arranged in a radial manner. These patches are often cut irregularly by the above-mentioned epidote veinlets. These ferruginous patches are evidently of secondary infiltration into the slate, and the epidote-bearing veinlets and patches are of still later formation, since the former are traversed by the latter.

A similar alteration is also typically developed in the green slate in the environs of the veins of Hyakken and Sekiei. There, veinlets and patches of epidote are abundantly found in the form of parallel bands along or across the indistinct bedding-planes.

Minor epidotization of the slate complex, microscopic as well as macroscopic, is observed very extensively in this district. The chloritized and silicified slate, already described, contains frequently more or less epidote in association with quartz grains.

The epidotization is evidently later than the chloritization of the slate, because epidote usually invades chlorite flakes, and veinlets of epidote cut the chloritized slate very sharply. On the other hand, it is clearly prior to the sideritization which is described in the next article, because epidote veinlets are traversed definitely by those of siderite.

The fact that crystals and grains of epidote always occur in association with quartz grains and the veinlets of epidote grade frequently into those consisting exclusively of quartz, indicates that the epidotization now under consideration is a special phase of the silicification, already considered.

(E) Sideritization of the slate.

The wall-rocks, particularly the silicified slate just adjacent to the veins, are commonly coloured reddish brown to brown, and are often penetrated by minute netted veins of a dark brown colour. This is one of the most striking characters recognizable by every keen observer. On close examination under the microscope, these rocks are always found to be intensely sideritized.

The reddish brown colour of the rock is due to the presence of abundantly and irregularly scattered flecks and innumerable microscopic netted veinlets of iron hydroxide. The iron hydroxide is yellowish brown in colour and shows indistinct aggregate-polarization-colours due to aggregation of microscopic grains. This is cryptocrystalline limonite.[1] That the limonite is derived from siderite by oxidation and hydration is clearly indicated by the following facts:—(1) Sometimes, in the interior of the flecks and veinlets of limonite a core of unaltered siderite is preserved; (2) the brownish veinlet often passes gradually into a vein consisting of strongly pleochroic carbonate (siderite); (3) in places, the country rock is heavily impregnated with siderite flecks, and is penetrated by netted veinlets of the same mineral, along the borders of which a change to brown hydroxide of iron is frequently observed (Pl. III., Fig. 1).

Small amounts of chlorite in irregular flakes have been formed in the stage of sideritization, since they are closely associated with siderite flecks in the sideritized rock and in the veinlets of siderite. On the other hand, the siderite flecks overlap the quartz grains in the silicified slate, and the siderite veinlets cut the same rock. The chloritized slate, too, is sometimes heavily impregnated with siderite and is cut irregularly by netted veinlets of the same mineral. Consequently, it is beyond all doubt that the sideritization has taken place subsequent to the intense chloritization and silicification of the country rock.

In the country rock adjacent to the veins, no alterations charac-

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1) A. F. Rogers, "A Review of the Amorphous Minerals," Journ. Geol., Vol. XXV., 1917, pp. 528–529.

teristic of pneumatolytic processes have been observed even under the microscope, though the diopsidization, a characteristic contact-alteration, is found rather rarely in the slate near, or at the contacts with, the dioritic rocks.

The chloritization, silicification and sideritization, which the country rock underwent very intensely and extensively, are characteristic of hydrothermal processes.

VIII. Quartzose Veinlets Cutting the Country Rock Adjacent to the Veins.

The country rock adjacent to the veins is commonly traversed by minute quartzose veinlets, sometimes showing a netted structure. Occasionally they contain cassiterite in association with muscovite and chlorite. In the following paragraphs are described those cassiterite-bearing veinlets found in the wall-rocks of the Daisen vein (Pl. VII., Fig. 3).

They are commonly less than 2 mm. in width, and cannot be distinguished with the naked eye from those of barren quartz. Cassiterite occurs in minute prismatic crystals, often rounded, and is the earliest crystallized mineral. Quartz occurs in idiomorphic and hypidiomorphic hexagonal prisms, its crystallization being hindered only by cassiterite crystals, which are usually embedded in it. Chlorite is the last deposited mineral and fills up the interstices between the crystals of cassiterite and quartz; it is the most abundant constituent. The chlorite is pale green in colour, fibrous to flaky radial in structure, showing a cross-bar between crossed nicols. It shows very weak double refraction, indicated by a gray interference colour. In close association with the chlorite, particularly along the selvages of the veinlets, a mineral in radiated fibers and flakes showing bright interference colours is found. It is almost colourless or very pale greenish and is distinguishable from chlorite only between crossed nicols. This mineral is most probably muscovite, which has crystallized chiefly along the selvages. The chlorite crystallized soon after the deposition of muscovite, and filled up all the interstices between the earlier minerals.

The veinlets under consideration ramify into stringers containing quartz and sporadic flakes of chlorite, and finally into those consisting exclusively of quartz grains. They are, therefore, contemporaneous in generation with the quartz veins and veinlets of the stage of the main silicification of the country rock. It is further suggested that the stage of the deposition of the main cassiterite-ore corresponds to the stage of silicification.

Veinlets and stringers of siderite-limonite and siderite-chlorite often cut the quartzose veinlets under consideration, though the former have a tendency to be ramified in the latter and to unite to larger veinlets in the silicified and sideritized country rock (Pl. VII., Fig. 3).

Pyrite filling the interstices between crystals and grains of quartz is sporadically found in the quartzose veinlets under consideration, and is sharply cut by the veinlets of siderite (Pl. VII., Fig. 4).

The country rock, green slate as well as carbonaceous, is extensively traversed, near the veins, by irregularly crossing veinlets of milky quartz, ranging in width up to 2 cm. or more. The quartzose veinlets containing sporadic cassiterite are also intricately cut by these barren quartz veinlets, as can be revealed under the microscope. In the environs of the Daisen and Daijukô vein groups, this phenomenon is most conspicuous. The veinlets of this category are barren, but contain insignificant quantities of bornite, chalcopyrite and zincblende in the form of small specks. They correspond probably to the barren quartz of the last stage of mineralization.

IX. Summary and Conclusions.

At the present time, it is generally accepted that tin veins can be deposited from pneumatolytic as well as hydrothermal solutions,[1] although those of pneumatolytic origin, containing characteristic pneumatolytic minerals such as fluorite, topaz, tourmaline, apatite and other fluorine and boron-bearing minerals, and accompanied by typical pneumatolytic alterations of the country rock, are of commoner occurrence.

That the veins under consideration were not formed under pure pneumatolytic conditions is indicated by the absence of characteristic pneumatolytic alterations of the wall-rocks. The slaty rocks in which the veins are enclosed are often intensely chloritized, silicified, epidotized and sideritized,[2] while no characteristic pneumatolytic minerals have been observed in them even under the microscope. These alterations are regarded to be characteristic of hydrothermal processes. Moreover, the veins themselves contain usually more or less siderite and chlorite, as can easily be revealed

1) The tin veins of hydrothermal origin have been reported by many investigators, the following being some typical examples:—

The tin-bearing veins of the transmetamorphic zone in the Zeehan Field of Tasmania (W. H. Twelvetrees and L. K. Ward, "The ore bodies of the Zeehan field," Tasm. Geol. Surv. Bull. 8, 1910).

The tin deposits of Mexico, in rhyolite surface flow and accompanied by topaz, quartz, chalcedony and opal, wolframite and bismuth ores (W. R. Ingalls, "The tin deposits of Durango, Mexico," Trans. Am. I. M. E., Vol. 25 (1895), pp. 146–163).

The tin veins of Northern Nevada, containing exclusively wood-tin as tin mineral, in association with opal, chalcedony, lussatite, tridymite, hematite, etc. (A. Knopf, "Wood tin in the Tertiary rhyolite of Northern Nevada," Ec. Geol., Vol. XI, 1916, pp. 652–661).

The cassiterite veins of the Suzuyama mine, Satsuma Province, Japan (T. Katō, loc. cit.).

2) Compare with the altered country rock of the Suzuyama veins (T. Katō, opt. cit., p. 149 et seq.).

under the microscope. These minerals occur, though rather sparingly, in ordinary cassiterite veins, and are most abundantly associated with hydrothermal tin veins, siderite, particularly, being of deposition, in most tin veins, in the last stage of pneumatolysis, or in pneumato-hydatogenetic or hydrothermal stages.[1]

The occurrence of chalcedony, evidently transformed from an opaline silica, as an important gangue-mineral is most instructive. This mineral is an extremely rare associate of tin-stone. Only a few examples of tin veins containing chalcedony have hitherto been reported,[2] and they all belong to the category formed under hydrothermal or allied conditions. As already fully discussed under the heading of "the deposition of the main cassiterite ore," the presence of chalcedony in the veins under consideration indicates that they were formed under hydrothermal conditions at a temperature below 360° C.

On the other hand, it must be noted that some minerals regarded as common associates of pneumatolytic deposits, such as fluorspar, wolframite and bismuth ores with sporadic microscopic topaz, are present in the veins. These minerals are, of course, of very common occurrence in the deposits formed at high temperatures, but may be deposited either from gaseous solutions or from superheated aqueous solutions containing soluble or gaseous compounds of fluorine, tungsten and bismuth. Typical hydrothermal veins containing scheelite, wolframite, fluorspar, bismuth ores, etc. are numerous even in this country.[3]

1) Ferguson and Bateman, loc. cit., p. 225; T. Katō, opt. cit., p. 161.

2) The Mexican deposits (Ingalls, loc. cit.); Those of Northern Nevada (Knopf, loc. cit.) etc.

3) The Kanagasé copper vein of the Ikuno mine, Prov. Tajima, containing scheelite, wolframite, native bismuth, etc.; the gold-silver veins of the Nishizawa mine, Prov. Shimotsuké, containing wolframite, bismuthinite, etc.; the copper veins of the Ashio mine, Prov. Shimotsuké, containing fluorspar, wolframite, apatite, etc.; and others.

The veins of this district are unique in the fact that the ore-bringer for them is a dioritic magma. Considering, however, that acid rocks can be derived from a basic magma by processes of differentiation chiefly due to fractional crystallization and settling[1] or by the expulsion of the residual fluid magma,[2] and that an acid differentiation-product with a composition of quartz-monzonite-pegmatite or aplite, akenobeite, is actually found as a small boss in this district, the genetic connection of the veins with the dioritic rocks is highly probable.

Summarizing all that has been stated, the copper-tin veins of the Akénobé district were deposited from hydrothermal solutions,[3] still containing fair quantities of mineralizers, at gradually decreasing temperatures, chiefly considerably below 360° C. The solutions had naturally a temperature far above the critical point of water (364° C.) and were gaseous in character, after emanation from the consolidating diorite magma. As they ascended through the surrounding slate complex, the rate of the fall of temperature was very rapid, and they soon changed to superheated hydrothermal solutions.

Lastly, the writer frankly states that he is quite in the dark as to whether the stannic oxide first separated from the solutions in the colloid state and subsequently became crystalline, or whether it crystallized directly as cassiterite by chemical reactions between stannic fluoride and other compounds.

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1) N. L. Bowen, "The Later Stages of the Evolution of the Igneous Rocks," Journ. Geol., Vol. XXIII., 1915, Supplement to No. 8, pp. 1-91.

2) A. Harker, "Natural History of Igneous Rocks," p. 323.

3) It should be borne in mind that tin oxide is, according to C. Doelter (Min. petrog. Mitt., Vol. 11, 1890, p. 325), perceptibly soluble in water at 80° C., and more so in the presence of sodium fluoride. This solubility is also indicated by several natural occurrences of tin-stone, as in an opaline deposit from a thermal spring in Selangor, etc. (S. Meunier, Compt. Rend., Vol. 110, 1890, p. 1083; J. H. Collins, Min. Mag., Vol. 4, 1880, pp. 1, 103, and Vol. 5, 1883, p. 121, etc.).

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Published May 10th, 1920.

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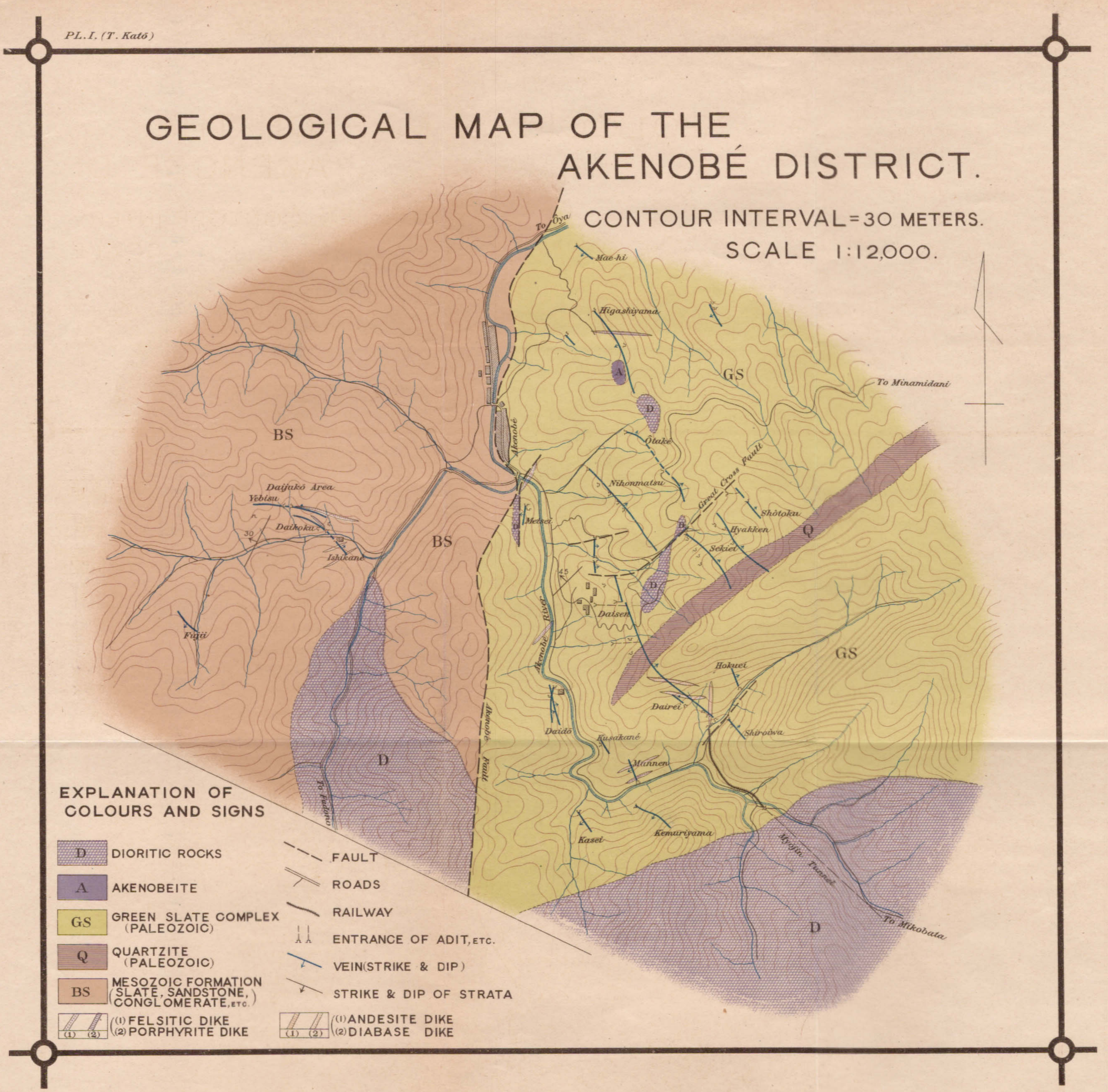
Copper-Tin Veins of the Akénobé District.

Plate I.

Geological map of the Akénobé vein district


GEOLOGICAL MAP OF THE AKENOBÉ DISTRICT.
CONTOUR INTERVAL = 30 METERS.
SCALE 1:12,000.
To Ôya
Maé-hi
Higashiyama
GS
To Minamidani
BS
Ôtaké
Nihonmatsu
Great Cross Fault
Shōtoku
Hyakken
Q
Sekiei
Daijakō Area
Yebisu
Daikoku
Ishikané
Meisei
Akenobé
Daisen
Akenobé River
Fujii
Hokuei
Dairei
Shirowa
Daidō
Kusakané
Mannen
D
Akenobé Fault
To Fukono
Kasei
Kemuriyama
Myōjin Tunnel
To Mikobata
EXPLANATION OF COLOURS AND SIGNS
D DIORITIC ROCKS
A AKENOBEITE
GS GREEN SLATE COMPLEX (PALEOZOIC)
Q QUARTZITE (PALEOZOIC)
BS MESOZOIC FORMATION (SLATE, SANDSTONE, CONGLOMERATE, ETC.)
(1) (2) (1) FELSITIC DIKE (2) PORPHYRITE DIKE
FAULT
ROADS
RAILWAY
ENTRANCE OF ADIT, ETC.
VEIN (STRIKE & DIP)
STRIKE & DIP OF STRATA
(1) (2) (1) ANDESITE DIKE (2) DIABASE DIKE

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Copper-Tin Veins of the Akénobé District.

Plate II.

Explanation of Plate II. (Photomicrographs)

Fig. 1. Phyllite, exposed near the Minamidani mine. Ordinary light Magnified 60 diameters. O, aggregate of graphitoid particles; S, micro. grains of quartz mixed with flakes of biotite and sericite, showing schistose structure.

Fig. 2. Green slate with veinlets of quartz and epidote. Q, quartz; E- epidote; Sl, carbonaceous slate containing abundant chlorite flakes. Ordinary light. Magnified 60 diameters.

Fig. 3. Silicified slate adjacent to the Daisen vein. Nicols crossed. Magnified 60 diameters. The thoroughly silicified rock, mingled with flakes of chlorite, is intricately traversed by quartz veinlets. Frequently, quartz veinlets grade into highly silicified rock-portions. Q, quartz grains composing veinlets.

Fig. 4. Chloritized slate (green slate) cut by quartz veinlets. Ordinary light. Magnified 60 diameters. Q, quartz veinlets; Ch, chlorite in aggregate of flakes; S, siliceous slate rich in quartz grains.

Fig. 5. Uralite-diabase, exposed near the Mannen adit, Akénobé. Ordinary light. Magnified 60 diameters. U, uralite; F, kaolinized feldspar. Note the intersertal (or, in places, ophitic) structure.

Fig. 6. Quartzite. Loc.—Near the Hyakken mine. Nicols crossed. Magnified 60 diameters. Note that this is composed of inequidimensional quartz grains.

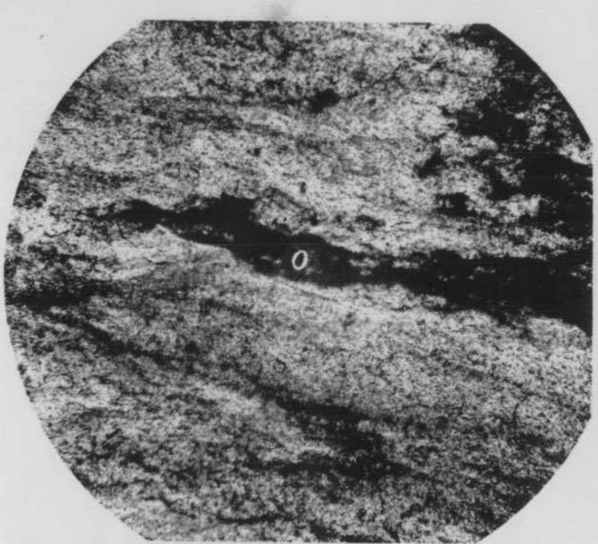


Fig. 1.

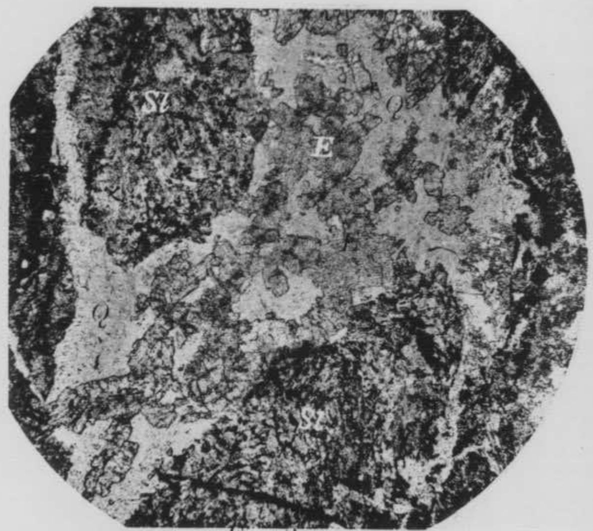


Fig 2.

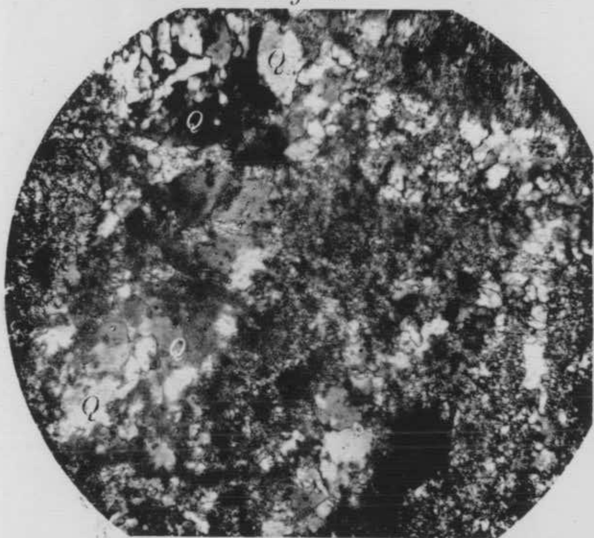
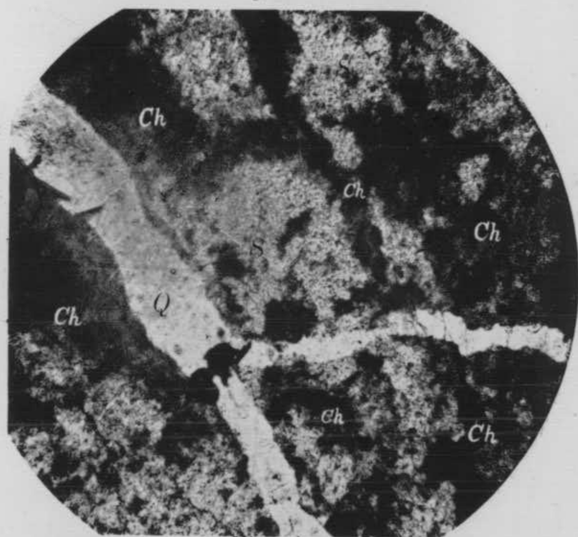


Fig. 3



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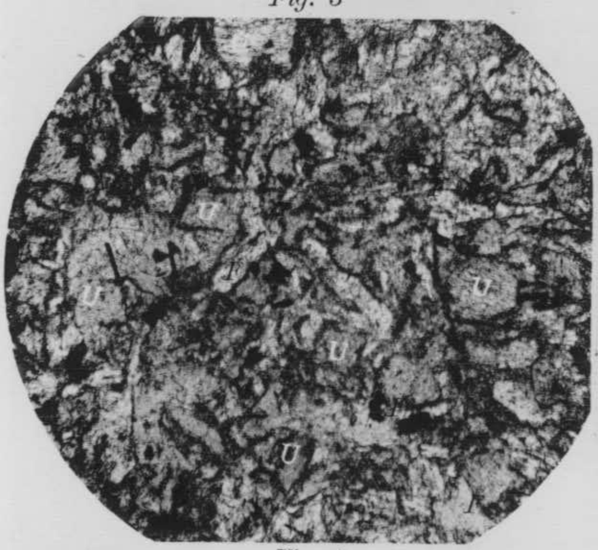

Fig. 5.

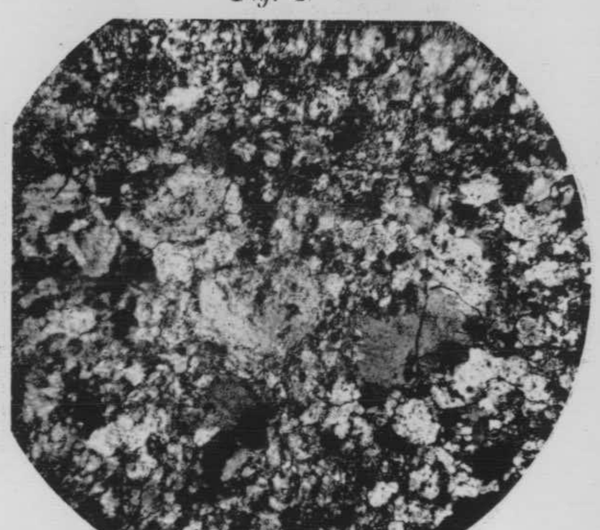
Fig. 6.

Katō : Copper-Tin Veins of Akénobé.

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Plate III.

Explanation of Plate III. (Photomicrographs)

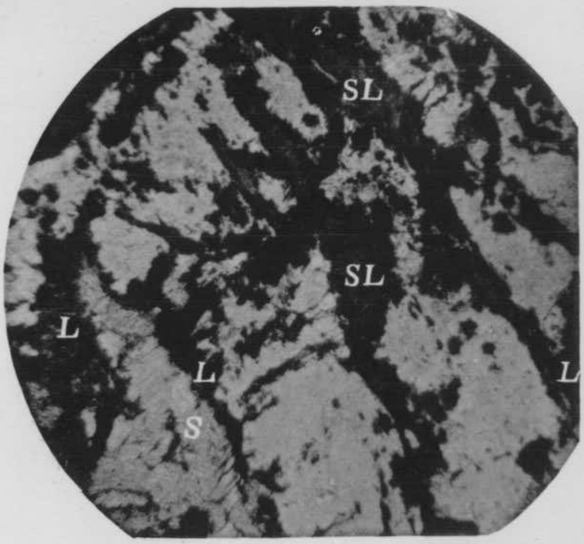
Fig. 1. Sideritized slate forming the walls of the Daisen vein. Ordinary light. Magnified 60 diameters. S, bleached slate; L, veinlets of limonite altered from siderite; SL, siderite veinlets altered to limonite along the selvages.

Fig. 2. Diopsidized slate (or diopside-hornfels), collected on the road-side between Akénobé and Fudono Pass. This is a portion of the rock, which is composed almost wholly of minute crystals and grains of diopside (D). Ordinary light. Magnified 60 diameters.

Fig. 3. Garnetiferous felsite-porphyry, forming a dike, found in the Yebisu adit. Ordinary light. Magnified 60 diameters. G, garnet; F, altered feldspar phenocryst.

Fig. 4. Pyroxene andesite, a dike cutting the Daisen vein. It is usually very altered. Ordinary light. Magnified 60 diameters. F, plagioclase; C, secondary calcite. No pyroxene is shown in this photomicrograph.

Fig. 5. Diabase, a dike cutting the Daisen vein. White and light-coloured parts are feldspar crystals (F) and altered feldspar; the dark-coloured parts are minute flakes of chlorite. m=Magnetite crystals. Ordinary light. Magnified 50 diameters.



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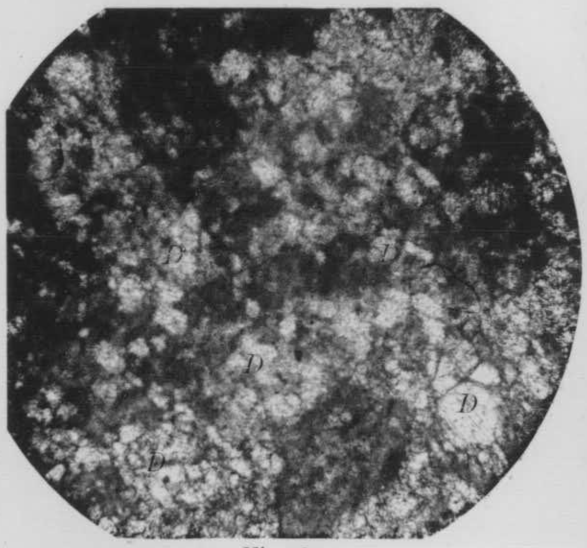


Fig. 2.

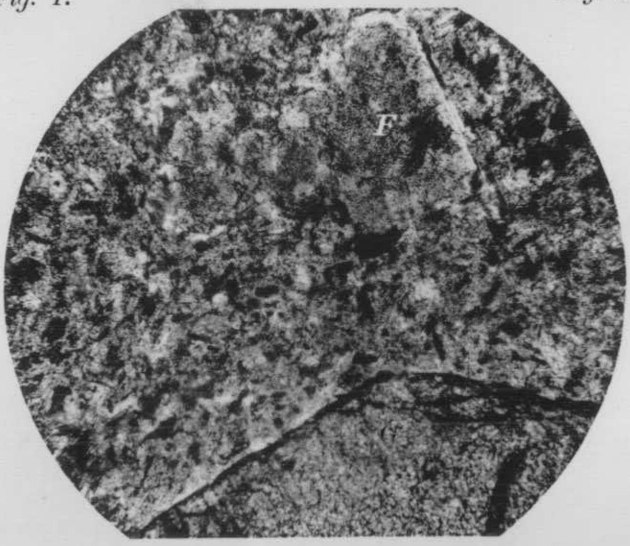


Fig. 3.

Fig. 4.

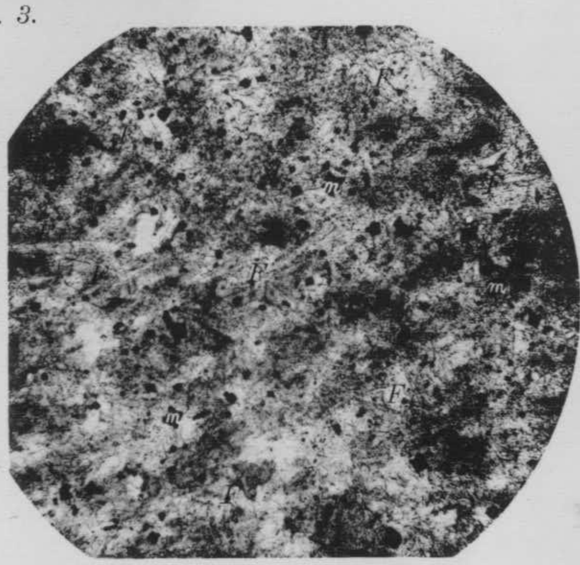


Fig. 5.

Katō: Copper-Tin Veins of Akénobé.

Plate IV

Explanation of Plate IV. (Photomicrographs)

Fig. 1. Diorite mylonite. Loc.—Eastern entrance of the Myôjin tunnel. Nicols crossed. Magnified 60 diameters. F, plagioclase mylonitized along the margin; M, cataclastic grains of plagioclase.

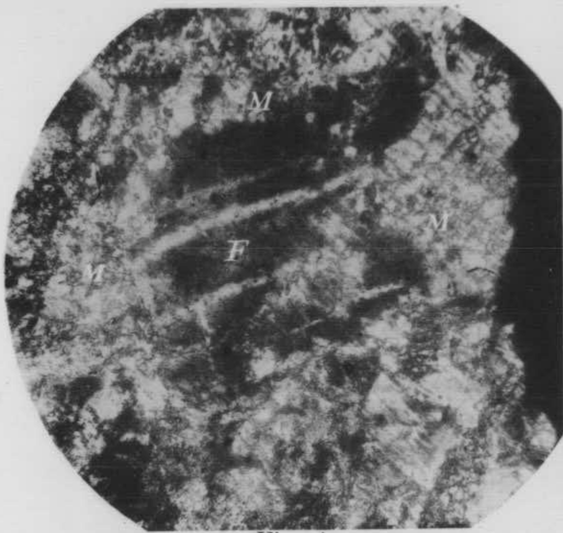
Fig. 2. Gabbroid diorite. Loc.—Near the entrance of the Sekiei adit. Ordinary light. Magnified 60 diameters. F, entirely kaolinized feldspar; H, hornblende.

Fig. 3. Akenobeite. Loc.—Higashiyama, Akénobé. Ordinary light. Magnified 60 diameters. F, feldspar (orthoclase and oligoclase); Q, granular quartz.

Fig. 4. Ditto between crossed nicols.

Fig. 5. Altered gabbroid diorite, exposed near the entrance of the Sekiei adit. Ordinary light. Magnified 60 diameters. H, hornblende partially altered to a fibrous actinolitic variety; F, entirely kaolinized feldspar with irregular boundaries.

Fig. 6. Schistose diorite. Loc.—Mikobata Pass. Ordinary light. Magnified 60 diameters. H, hornblende; F, feldspar, granulated and mingled with sericite fibers; P, pyrrhotite.



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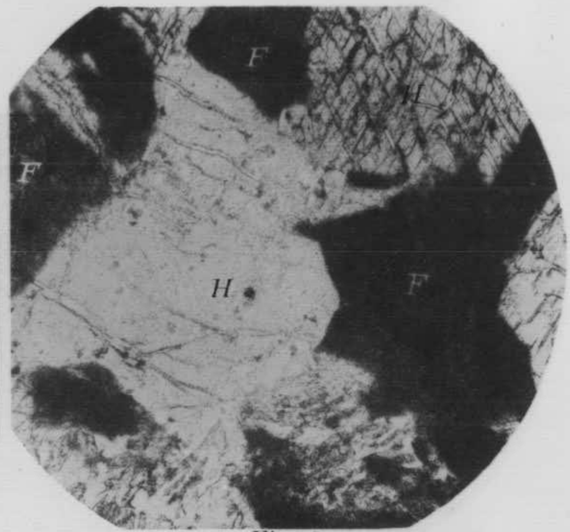

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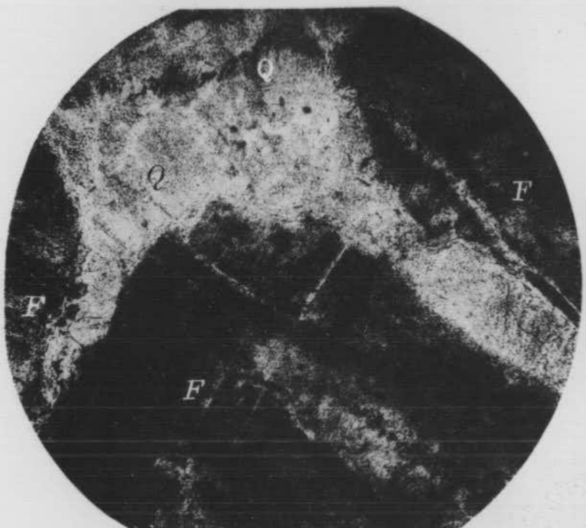

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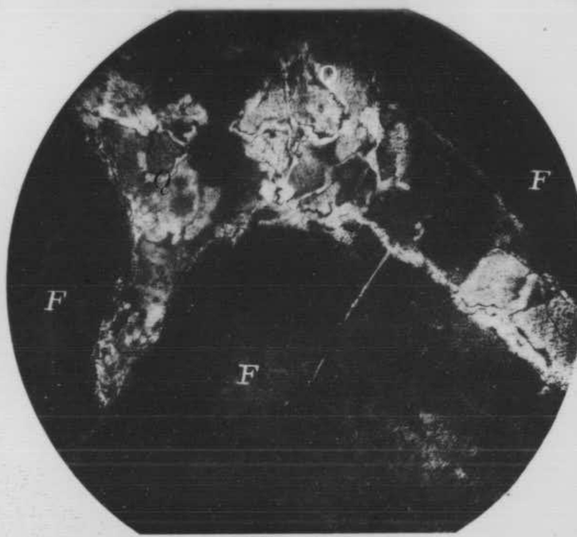

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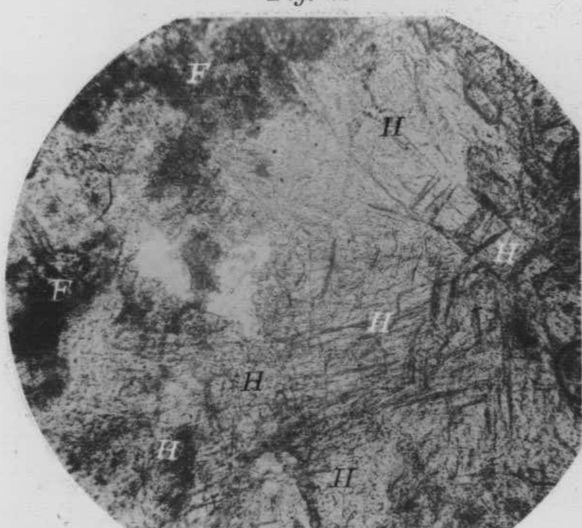

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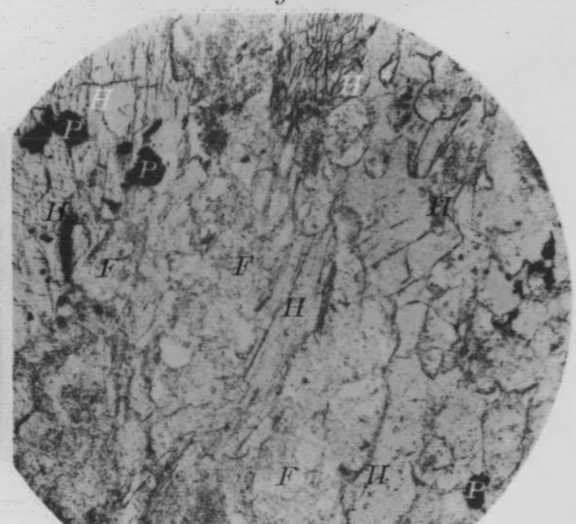

Fig. 6.

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Plate V.

Explanation of Plate V.

Fig. 1. Quartzose wolframite-cassiterite ore from the Daisen vein. 1/2 natural size. Q, quartz; *w*, thin plate of wolframite. Cassiterite is enclosed in quartz as microscopic crystals and grains.

Fig. 2. Ring-ore from the Daisen vein. Natural size. R, silicified or partially sideritized rock-fragment; Q, quartz crust; T, layer rich in cassiterite; C, chalcedony crust. Note a streaky cassiterite zone in the second quartz crust.

Fig. 3. Another large piece of ring-ore from the Daisen vein. 1/4 natural size. R = ore-ring.

Fig. 1.

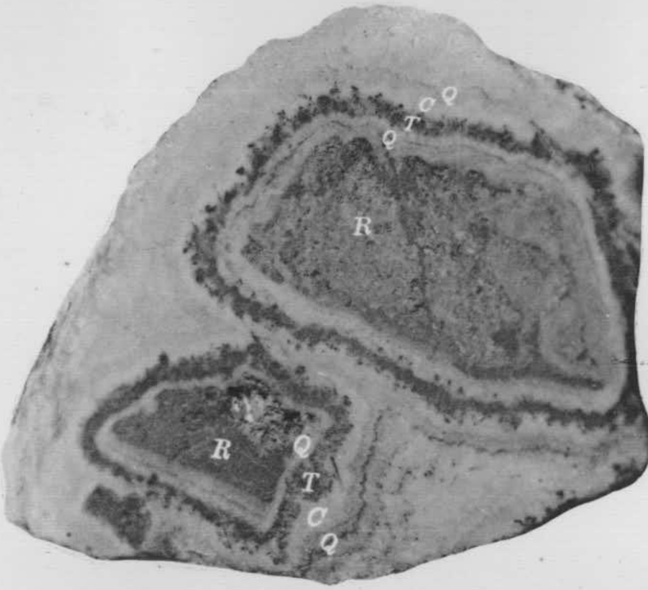

Fig. 2.

Fig. 3.

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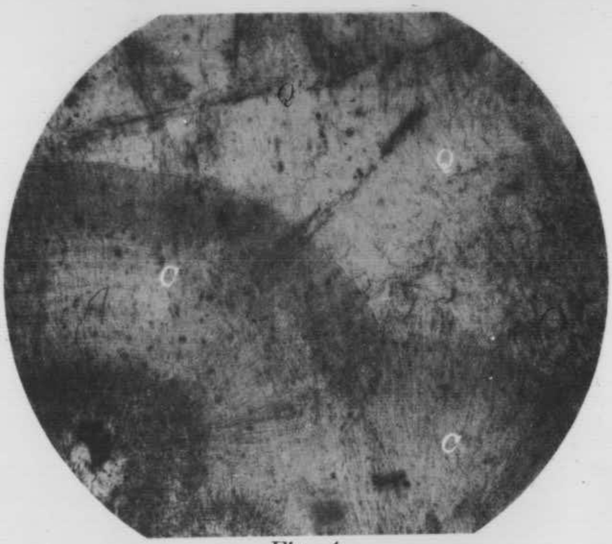
Plate VI.

Explanation of Plate VI. (Photomicrographs)

Fig. 1. Chalcedony crust of the ring-ore from the Daisen vein. Ordinary light. Magnified 70 diameters. Note the radial and fibrous structure of chalcedony.

Fig. 2. Ditto between crossed nicols, showing more clearly that chalcedony consists of radiating fibers. C, chalcedony; Q, quartz grains of later deposition.

Fig. 3. Thinner crust of chalcedony in another specimen of ring-ore. S, sulphides, chiefly bornite in association with minute crystals of cassiterite in the earliest crust of quartz; C, chalcedony crust consisting of globular chalcedony; Q, later crust of quartz. Ordinary light. Magnified 50 diameters.



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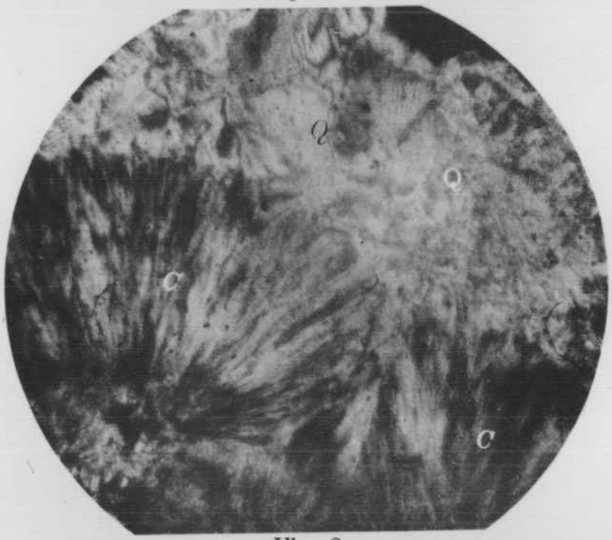

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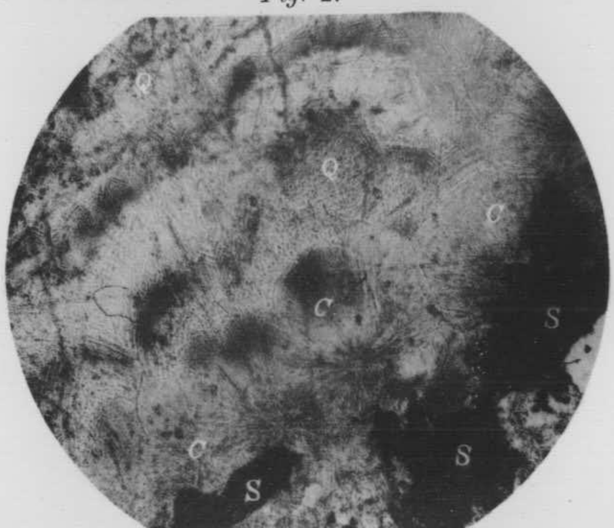


Fig. 3.

Katō : Copper-Tin Veins of Akénobé.

T. KATŌ:

Copper-Tin Veins of the Akénobé District.

Plate VII.

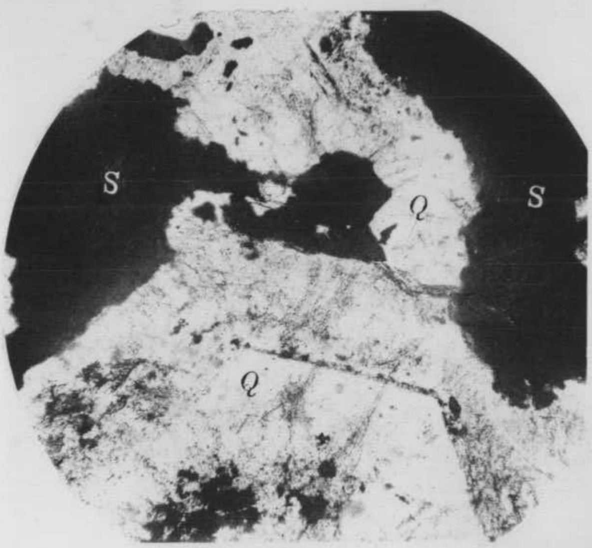
Explanation of Plate VII. (Photomicrographs)

Figs. 1, 2. Copper-tin ore from the Daisen vein. Ordinary light. Magnified 60 diameters. Q, quartz showing zonal structure; S, chalcopyrite; T, cassiterite in aggregate of minute crystals; To, topaz.

Fig. 3. Cassiterite-bearing veinlet cutting the wall-rock of the Daisen vein. Ordinary light. Magnified 50 diameters. Sl, more or less silicified slate; T, cassiterite; Q, quartz; C, chlorite; S, siderite veinlet; M, muscovite.

Fig. 4. Quartz veinlet in the wall-rock of the Daisen vein. Ordinary light. Magnified 50 diameters. Q, quartz; P, pyrite filling the interstices between quartz crystals; S, siderite veinlet cutting the quartz veinlet; Sl, chloritized slate.

Fig. 5. Wolframite-cassiterite ore from the Daisen vein. Ordinary light. Magnified 50 diameters. Q, quartz; W, wolframite; T, cassiterite crystal; W′, alteration-product of wolframite (scheelite).



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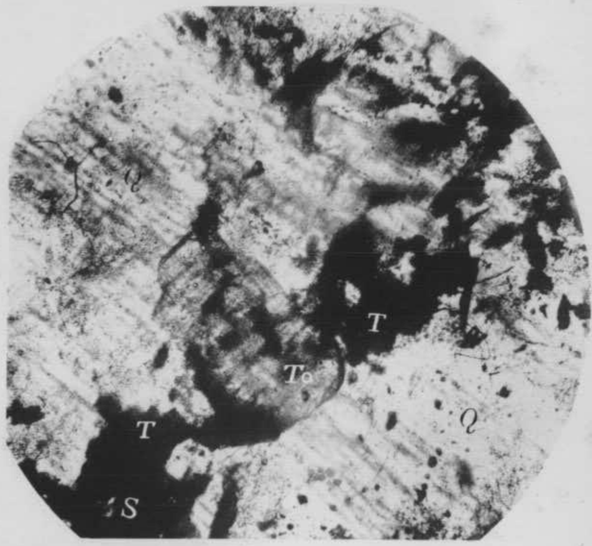

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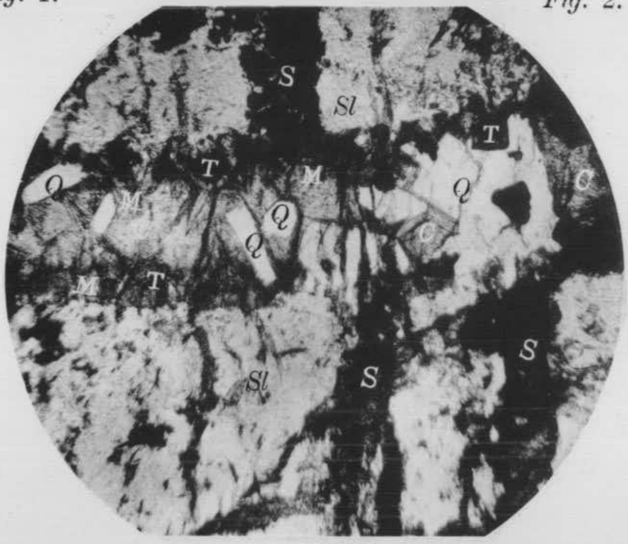

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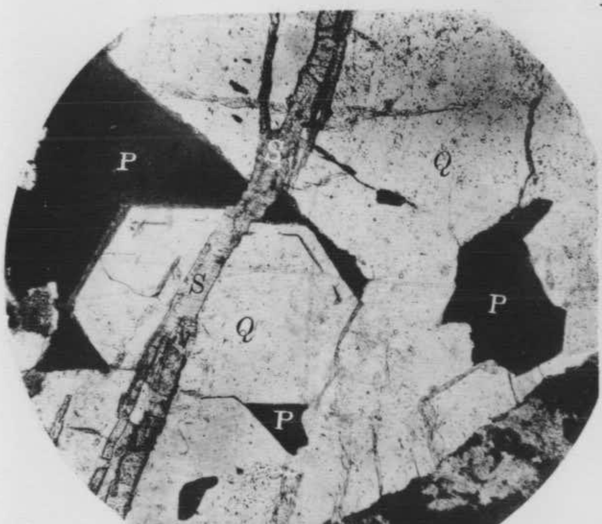

Fig. 4.

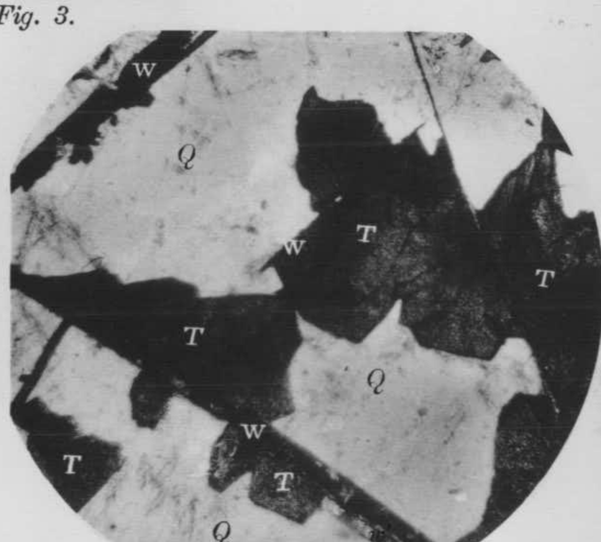

Fig. 5.

Katō: Copper-Tin Veins of Akénobé.