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THE CONTACT METAMORPHIC ORE DEPOSITS
IN THE ENVIRONS OF THE OFUKU MINE,
PROVINCE OF NAGATO, JAPAN

By

Jun SUZUKI

With 10 Plates and 9 Text-Figures

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I. INTRODUCTION

The Ofuku mining district⁽¹⁾ in the province of Nagato (Yamaguchi Prefecture) is located in the most south-westerly part of the mainland of Japan, and Ofuku,⁽²⁾ a small central town of the district, lies some 27 km. north of the Asa⁽³⁾ Station on the Sanyō Railroad Line. In this district a small mass of dioritic rock and some dikes have intruded into the overlying sedimentaries and as a consequence of contact metamorphism, many ore deposits have been formed in the Palaeozoic limestones. These deposits surround the dioritic mass in an elliptical arrangement extending in a north-south direction though they show marked characters respectively on account of the different effect of the intrusives.

The topography of the district which belongs to the so-called Chûgoku type,⁽⁴⁾ can be distinguished, according to the surface features, into three different regions, viz.: the mountainous region, the plateau region and the alluvial plain.

The mountainous region, the western half of the district, consists of two mountain ranges running in a slightly northeast direction. Their orogenic axial direction is approximately parallel to the general strike of the Palaeozoic formation which is developed extensively in the district. The summits of the two parallel mountain ranges are chiefly composed of hard layers of Palaeozoic chert which is resistant to denudation and erosion. Gampisan,⁽⁵⁾ the maximum elevation of the ranges, is 580 m. above sea-level. These ranges are transient on both ends and on the western side, to the lower hills, composed of Mesozoic sedimentaries.

The plateau, called Ofukudai,⁽⁶⁾ in the eastern part of the district, is composed wholly of limestone of Palaeozoic formation, with an average height of 300 m. It is bordered on its western margin by steep cliffs 70° in inclination along the Asa-gawa valley. The surface of the plateau is generally flat but locally it shows a typical Karst topography. Numerous sink-holes (dolinas) 30-100 m. in diameter, are scattered on the surface. No characteristic subterranean caves are to be found around the Ofuku plateau. Topographically

(1) It takes its name from the Ofuku mine which marks the largest deposits in the district.

(2) 長門國美禰郡於福村於福 (3) 厚狹

(4) B. Koro: The Physiographic Type of Chûgoku. (In Japanese). Publications of the Imp. Earthq. Inv., No. 63 (1909) p. 1-15.

(5) 雁飛山 (6) 於福臺

the plateau is similar to Akiyoshidai,⁽¹⁾ lying to the east of the district. It is reasonable to regard this plateau as a western continuation of Akiyoshidai, though it is markedly separated by the deep gorge of the Kama-river. Many residual deposits of ferruginous manganese ores are scattered on the limestone plateau. These deposits seem to have no connection with any igneous rocks.

The narrow alluvial plain along the Asa-gawa valley extends to a length of about 5 km. from north to south with a width of about 1 km. from east to west. The plain locally breaks into the mountainous region on the west side, making the narrow valleys along the small tributaries of the river Asa. A low river terrace, though on a small scale, can also be observed at the eastern foot of the dioritic hills. On the western side of the mountain ranges, some alluvial plains very small in area develop here and there.

In short it is noticeable that these topographic features coincide with the geologic structures of the district.

The history of the geological investigation of the area under discussion in this paper, opens with Nishimura's work⁽²⁾ (1903) in which only a general description of geology is given with a few references to ore deposit. In 1907 was published the sheet "Yamaguchi" of the geological map on the scale of 1:200,000 which was made by T. Suzuki.⁽³⁾ A short description on the geology and ore deposit of the Ofuku district is in its explanatory text. In the same year N. Fukuchi⁽⁴⁾ described the Sanjô deposit with special reference to the mineral paragenesis. In 1913 T. Kato⁽⁵⁾ published a full account of the geology and ore deposit of the Ofuku mine. It gives the first detailed treatment of the ore bodies in the district. Eight

(1) Akiyoshidai (秋吉臺) is the largest limestone plateau in Japan detailed studies of which have been published by many authors:—N. YAMASAKI: On the Karst Topography of Akiyoshi Plateau, Prov. Nagato. (In Japanese). Jour. Geol. Soc. Tokyo. Vol. XIII, (1906), p. 337-344. T. KATO: The Ore Deposits in the Environs of Hananoyama near the Town of Oda, Province of Nagato, Japan. Jour. Meiji Coll. Techn., Vol. I. No. 1 (1916), pp. 2-4. Y. OZAWA: Geologic History, Topography and Ground Water in the Akiyoshi District, Prov. Nagato. (In Japanese). Chirigaku Hyoron: The Geographical Review of Japan, No. 1-3 (1925).

(2) M. NISHIMURA: Geology of the Northern Part of Nagato. Ms., 1903.

(3) T. SUZUKI: The Explanatory Text to the Yamaguchi Sheet. (In Japanese). Imp. Geol. Surv. of Japan, 1907.

(4) N. FUKUCHI: Mineral Paragenesis in the Contact Metamorphic Ore Deposits, found in Japan. Beiträge zur Mineralogie von Japan, herausgeg. von T. Wada, Nr. 3 (1907) pp. 88-89.

(5) T. KATO: Mineralization in the Contact Metamorphic Ore Deposits of the Ofuku Mine, Prov. Nagato, Japan. Jour. Geol. Soc. Tokyo, Vol. XX, 1913, pp. 13-32.

years later J. T. Chang⁽¹⁾ was engaged in the study of the geology and ore deposits in the area in association with the present author and he wrote a description of those subjects. In 1922 and 1923 T. Ogura⁽²⁾⁽³⁾ investigated the extensive area of the district and published a further contribution on the ore deposits and the new sheet "Yamaguchi" of the geological map on scale of 1:75,000 with its explanatory text.

The geological field work, on which this report is based, was done during the whole summer of 1921 and several days in 1922 and 1930 under the kind direction of Prof. T. Kato. The geological map of the Ofuku mining district accompanying this report, shows an area of about 5.5 by 5 square kilometers, bounded on the West by longitude 131°10' E. and on the North by latitude 34°05' N.

It is of interest that the general aspect of the geology and ore deposits in this district, is much like that in the environs of Hananoyama⁽⁴⁾ which was fully studied by Prof. T. Kato. His report has been of great use in preparing the present work.

The writer wishes to express his sincere gratitude to Prof. T. Kato for his kind criticisms and valuable suggestions on the field and in the laboratory during the course of the work. Acknowledgment must also be made to Prof. S. Tsuboi and the late Dr. Y. Ozawa, to whom the writer is indebted for many helpful suggestions on the petrological and stratigraphical studies in the district.

II. GEOLOGICAL SKETCH

General Features

The Ofuku mining district is composed, (cf. the annexed geological map) of the Palaeozoic and Mesozoic sedimentaries and a large diorite mass probably of late Mesozoic age. Besides these, there are numerous dikes which are considered to be derived from the above mentioned intrusive mass. There are no post-Mesozoic sedimentaries in the district except some Alluvial deposits.

(1) J. T. CHANG: The Geology and Ore Deposits of the Ofuku District, Nagato. MS. (1922).

(2) T. OGURA: Explanatory Text of the Geological Map of Japan, Sheet 263 (Yamaguchi). (In Japanese). Imp. Geol. Surv. Japan (1923).

(3) T. OGURA: The Ore Deposits in the Environs of the Ofuku Mine. (In Japanese). Imp. Geol. Surv. of Japan, Report No. 82, (1922), p. 19-48.

(4) T. KATO: The Ore Deposits in the Environs of Hananoyama near the Town of Oda, Province of Nagato, Japan. Jour. Meiji Coll. Techn., Vol. I. No. 1, (1916), p. 1-92.

In the immediate vicinity of the intrusive rocks, the effects of contact metamorphism and of mineralization are conspicuous and valuable ore bodies have been discovered within this zone. In the sedimentaries such as sandstone, chert and slaty rock, the change is, as a rule, relatively slight, but in the limestone it is exceedingly great.

The order and thickness of the sedimentaries are shown in the section in Fig. 1.

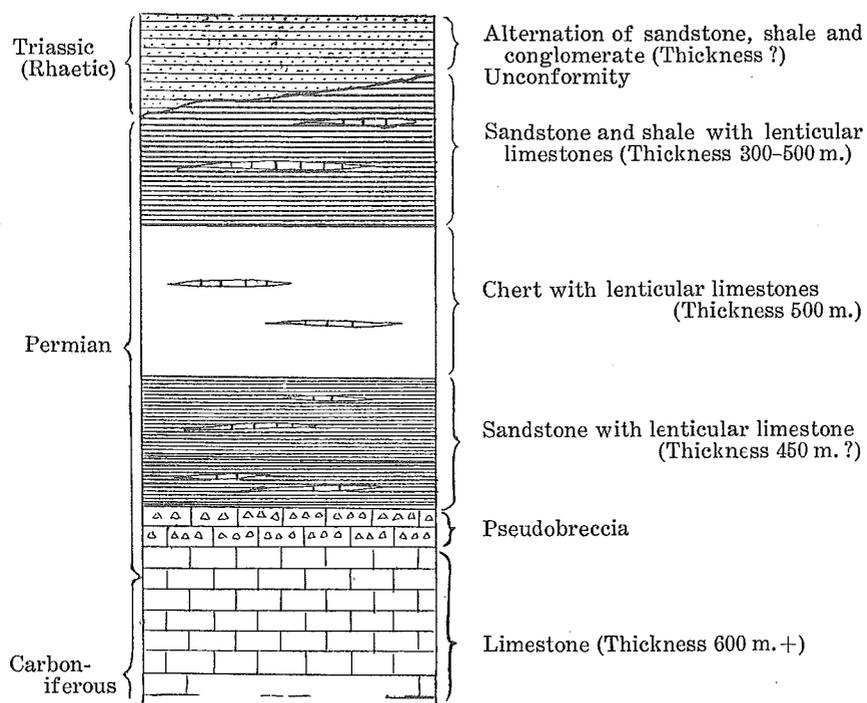


Fig. 1. Columnar section, showing the order of the sedimentary rocks in the Ofuku mining district.

Palaeozoic Formation

The Palaeozoic formation or so-called Chichibu System, occupies the greater portion of the district and is chiefly composed of sandstone, shale, chert and limestone. Good exposures of these rocks in the district make the determination of strikes, dips and thickness quite simple. The general strike of these layers is N. 15° E.

and the dip ranges at a high angle of from sixty five to eighty degrees toward the east side. No unconformity is discovered between these layers. As measured in the cross section (Fig. 1), the thickness of these layers, with some exceptions, can be determined accurately.

The many fossils found in the limestone belts indicate that the fundamental sedimentaries⁽¹⁾ in this district belong to the period from the Upper Carboniferous to the Permian age. (Pl. XIV, Fig. 1 and Fig. 2.)

As delineated on the geological map, several faults transversed the Palaeozoic region in the district. Considered broadly they present roughly two common directions, from east to west and from north to south, and they are generally well disclosed by the topographic features. For example, the direction of the latter type clearly coincides with the course of the Asa river. It is believed that the faultings in the district took place at the end of the Palaeozoic age. For in the western part of the district, the faults are all covered with the Mesozoic formation.

Limestone.—Limestone plays an important role in the district, forming the extensive plateau-land, and sometimes occurring as thin lenticular masses interstratifying in chert, sandstone and shale. It is noticeable that these limestones were of great service to ore deposition for they were always susceptible to a degree to metasomatic replacement by the hydrothermal solution which emanated from the intrusive rocks in contact with the limestones. (See Fig. 6). The unaltered part is very compact and fossiliferous, but the neighbouring part of the igneous contact, is recrystallized throughout into a granular saccharoidal limestone, containing no traces of organic remains.

Sometimes it contains many silicate minerals such as garnet, diopside, wollastonite, etc. which occur as metamorphic products between limestone and intrusive rocks. These minerals are ordinarily accompanied by many metallic ores.

The width of the zone of alteration in the limestone is variable and at the outer part it merges gradually into the unaltered limestone. Under the microscope, the saccharoidal limestone is composed of pure calcite grains showing a typical mosaic structure.

(1) Though no leading fossils have been found in the chert and sandstone, it is clear that these layers are to be regarded as the Permian age on account of the fossiliferous lenticular limestone interstratified with them.

A thick limestone layer occupies the eastern half of the district composing the plateau region with an average height of 300 m. The bedding planes of the limestone layer cannot be definitely determined, but they are seen to be clearly conformable to the other sedimentaries if we take into consideration the horizons of the index fossils and their relation to the other layers such as sandstone and chert. The average thickness of the limestone may be about 600 m. The many horizons in the limestone contain abundant fossil remains such as foraminiferas, crinoid stems, corals, brachiopods and some bryozoa.⁽¹⁾

The chemical analyses of the unaltered limestones from various places in or near the district are as follows.⁽²⁾

TABLE I.

	A	B	C	D
SiO ₂	7.42	1.02	0.33	0.18
Al ₂ O ₃ } Fe ₂ O ₃ }	2.33	1.95	1.82	0.19
MgO	0.46	1.08	0.34	0.54
CaO	48.56	49.85	53.74	55.40
Na ₂ O	—	—	—	0.09
P ₂ O ₅	2.53	2.08	—	—
Ig. loss	38.65	43.40	43.88	43.84
Total	99.95	99.38	100.11	100.24

- A. Limestone, Tobinosu, Akiyoshidai, Nagato.
- B. Limestone, Kaerimizu, Akiyoshidai, Nagato.
- C. Limestone, Shiraiwa, Ômine-mura, Nagato.
- D. Limestone, Kyôzuka, Akiyoshidai, Nagato.

The results of these analyses show that the limestone of this district is generally pure calcium carbonate, low in silica, magnesia, iron and other impurities.

(1) Y. OZAWA: Paleontological and Stratigraphical Studies on the Permo-Carboniferous Limestone of Nagato. Part. II, Paleontology. Jour. Coll. Sci. Imp. Univ. Tokyo. Vol. XLV, Art. 6 (1925), pp. 1-90.

(2) The former three (A, B and C) were made by the students of the Chemical Institute, Tokyo University, under the direction of Dr. K. Kimura, and the last one (D) is quoted from the Koyama's work. (I. KOYAMA; Nippon Sekizai Seigi (Buildingstones of Japan) 1931, Tokyo, p. 282).

The thickness of the lenticular limestones in chert, sandstone and shale, varies with remarkable rapidity, ranging from less than one foot to more than forty feet. In general these limestone lenses are closer to the intrusive mass than the plateau limestone in the field and it is of especial interest, for the many valuable ore deposits of the district such as the Ofuku deposits and Sanjô deposits, are all localized in these lenticular limestones.

The unaltered part of the lenses are characterized by containing numerous remains of foraminiferas and others which are of great service to the determination of the stratigraphical position of chert, sandstone and shale layers. It is reasonable to believe that many lenticular beds of limestone must have been deposited in the circular depression of the surface of the other layers.

Sandstone and Shale.—Three zones of sandstone in the district are arranged in parallel strikes of N. 20°E. dipping with a steep angle toward the east side. They occupy conformably the stratigraphic interval between chert and shale. The sandstones are generally dark gray in colour and show a hard, compact slaty-appearance. But near the intrusive rocks they have suffered extensive alterations and changed into black hornfels due to the action of mineralizing solutions.

Under the microscope, the unaltered sandstone is composed of fine grains of quartz and feldspar accompanied with some carbonaceous matter. The metamorphosed part, hornfels, shows a holocrystalline structure composed of fine grains of quartz and feldspar mingled with exceedingly abundant flakes of biotite. Sometimes it contains a few grains of garnet crystal though they show no definite form. (Pl. XIV, Fig. 4). The optical data of the chief minerals in the hornfels from Hirakunigi are as follows: feldspar ($n_1 = 1.541$ and $n_2 = 1.545$ on 001), biotite ($Z = Y =$ reddish brown, $X =$ pale brownish yellow, $Z = Y > X$ and $\gamma = 1.640$)

The hornfels toward the intrusives becomes coarser and coarser in grain and biotite flakes increase. But some parts give place to a highly siliceous one showing a disappearance of mafic mineral. Pyrite is a common constituent of the hornfels and locally it has been greatly enriched in limonite which indicates the former existence of pyrite. Aluminous minerals such as cordierite and andalusite have never been found in the metamorphosed sandstone in the district.

Near the Ofuku mine, a portion of the sandstone layer is immediately overlying the intrusive mass and it has been so disturbed

by decomposition into loose fine sand and by many great faultings that the bedding plane is almost thrown into confusion and its true thickness cannot be definitely calculated though probably it is not less than 500m. The other two zones of sandstone are rather fresh in character, showing a fine bedding plane, which indicates that these layers have not suffered important alterations by intrusive rocks.

Chert.—As has been described, two layers of cherts have remained forming the summits of the parallel mountain ranges owing to their durable characters resisting to erosion and denudation. They are interstratified conformably with the layers of sandstone and evidently belong to the same period of deposition. These layers have a general strike of N. 20° E. dipping eastward at a high angle of 60-80 degrees.

As the exposure of the chert layers are very distinct, occasionally forming cliffy walls owing to the sparseness of vegetation, it is quite convenient in determining the dips and strikes. In general the chert in this district varies in colour from light gray to dark gray, showing a conchoidal fracture. Near the igneous contact it has altered to the flinty rock due to the effect of recrystallization by contact metamorphism. It is very compact and passes in colour from whitish gray to yellowish brown.

Under the microscope, it is made up essentially of minute quartz grains with a diameter of 0.4 mm. or less, accompanied by a small quantity of feldspar and fibrous chalcedonic materials. Some quantity of xenomorphic grains of calcite and brownish films of limonite are also embedded in the chert. (Pl. XIV Fig. 3).

Sometimes many fibrous wollastonite clusters are developed along the cracks of the metamorphic chert. The origin of the mineral is due to the metasomatic action of the siliceous hydrothermal solution on the calcareous chert. (Pl. XIV, Fig. 5).

The western layers of the chert do not exhibit the more intense phase of metamorphism over extensive areas and sometimes fresh parts which have not suffered from mineralizing solutions, contain small quantities of radiolarian remains, though in the part near the intrusive rocks the fauna is extremely scanty.

As already mentioned, the chert layers interstratify with many thin lenticular beds of fossiliferous limestones which indicate that the geological age of the chert layers in the district is distinctly referable to the Premian age.

Age and Stratigraphic Relations of the Palaeozoic Formation.—It is indeed a cause of rejoicing that the settlement of the complicated stratigraphic relations of the Palaeozoic formation in the district, has been so ably completed by the late Dr. Y. Ozawa⁽¹⁾.

After his accurate comparison of the many fossils which have been collected by him at numerous places in the district, he divides the whole Palaeozoic formation into four zone, viz., *Neoschwagerina*, *Schwagerina*, *Fusulinella* and *Lonsdaleia* zones, from upper to lower. Every zone has furnished sufficient index fossils to prove with certainty that the Palaeozoic formations in the district were deposited during the period from the Carboniferous to the Upper Permian age. It is more worthy of notice that a collection from the highest point of the Ofuku plateau contains *Fusulinella bocki* Møller and others which are representatives of the Middle Carboniferous age, but the lenticular limestones intervening between the shale, sandstone or chert which lie under the limestone plateau, contain *Neoschwagerina craticulifera* Schwager etc., of the important index fossils to the Permian.

Judging from these stratigraphic and palaeontologic evidences, Y. Ozawa has concluded that the upper half of the Palaeozoic formations in the district, has been entirely reversed, and that the age of reversing might have been at the end of the Permian.⁽²⁾

Mesozoic Formation

The Mesozoic formation is widely distributed in the western part of the district and is essentially composed of the alternation of black shale, sandstone, conglomerate and coal seam. This formation has a general strike of N. 10°E. and dip of 30° toward west.

The sandstone in the formation is hard and compact showing a light grayish colour. Sometimes the sandstone layers interstratify with thin slaty rocks which contain locally some species of fossil

(1) Y. OZAWA: A Stratigraphical Study of the so-called Upper Chichibu System (Palaeozoic) with the Akiyoshi Limestone. (In Japanese). Jour. Geol. Soc. Tokyo. Vol. XXX (1923), p. 227-243 and Paleontological and Stratigraphical Studies on the Permo-Carboniferous Limestone of Nagato, Part II. Paleontology, Jour. Coll. Sci. Tokyo Imp. Univ. Vol. XLV, Art. 6 (1925). The Post-Palaeozoic and Late Mesozoic Earth-movements in the Inner Zone of Japan. Jour. Fac. Sci. Tokyo Imp. Univ. Sec. II, Vol II, Vol. I, Part 2. (1925).

(2) Y. OZAWA: The Post-Palaeozoic and Late-Mesozoic Earth-movements in the Inner Zone of Japan. loc. cit.

plants. The thin layers of conglomerate lie between those of sandstone and they are generally composed of pebbles 0.5 to 2.5 cm. in diameter, of the Palaeozoic rocks, such as chert, slaty sandstone, cemented together by siliceous sandy matter.

The six workable coal seams are intercalated in sandstone and they are being worked at present in Ominé⁽¹⁾, Tsubota⁽²⁾ and Yokomichi⁽³⁾. The thickness of the coal seams is generally from 1 to 1.5 m., but often it reaches 5 m.

In former times no index fossils had been found in the Mesozoic formation in the district and the exact geological age had been left undetermined. But lately, in the upper shale of the Ominé coal-field, T. Ogura⁽⁴⁾ found some species of fossil plants such as *Cladophlebis haiburnensis* (L. & H.) and *Podozamites* sp. (distan?) from Ojigase near Ominé. Y. Ozawa⁽⁵⁾ also found fossil plant *Cycadocarpidium swabii* Nathorst which is the characteristic fossil of the Rhaetic formation, in the same sedimentaries. Accordingly there is no doubt that the formation has close relation with the Yamanoi plant fossil bearing series, studied by M. Yokoyama⁽⁶⁾. T. Kobayashi⁽⁷⁾ has recently proposed the name "Miné formation," for the coal bearing formation and he decided palaeontologically that the formation may represent nearly the whole of the Upper Trias.

As a whole, the sedimentaries of the Mesozoic formation in the district are not intensely metamorphosed widely over the extensive area, but in the vicinities of the intrusions of the dikes near Kamitashiro⁽⁸⁾ and Kuwahara⁽⁹⁾, the shale and sandstone changed into compact hornfels which is considered to be a metamorphic product. This phenomenon is of great service in showing that the intrusion of the igneous rocks in the district took place at least in the post-Rhaetic age.

(1) 大嶺 (2) 坪田 (3) 横道

(4) T. OGURA: Explanatory Text of the Geological Map of Japan, Yamaguchi Sheet, (1923), p. 8. (In Japanese).

(5) Y. OZAWA: On Limestone Conglomerates, Limestone Breccias, Spotted Limestones, and Pseudobreccia, Associated with Limestone Beds. (In Japanese), and The Post-Paleozoic and Late-Mesozoic Earth-Movements etc. loc. cit. p. 94, Jour. Geol. Soc. Tokyo. Vol. XXIX (1922) p. 491.

(6) M. YOKOYAMA: Mesozoic Plants from Nagato and Bitchu. Jour. Coll. Sci. Imp. Univ. Tokyo. Vol. XX, Art. 5 (1905).

(7) T. KOBAYASHI: Note on the Mesozoic Formations in Prov. Nagato, Chugoku, Japan. Jour. Geol. Soc. Tokyo. Vol. XXXIII, (1926), p. 1-9.

(8) 田代

(9) 桑原

Alluvial Deposit

The recent deposits in the district under consideration developed between the plateau and the mountain region. The upper part of the formation is composed of the accumulation of alluvial sediments which were derived from the erosional substance of the local mountains washed down by the River Asa and its small tributaries. The lower layer of the formation is made up of a sand and clay bed containing abundant carbonized plants. From these data, it is conceivable that these beds were deposited in the lake water which filled up the eroded surface of the intrusive mass and the Palaeozoic formation. Besides we see the validity of this suggestion added to by the topographic feature of the district shown in the accompanying geologic map.

III. THE INTRUSIVE COMPLEX

General Features

The principal igneous rock in the district includes the intrusive mass of dioritic rock which occurs as a boss breaking the forementioned Palaeozoic and Mesozoic formations, sending out many dikes at a short distance from the margin.

The mass is apparently semi-elliptical in shape, a little over 3 km. in the greatest length from north to south and a little more than 1 km. in width from east to west. That is, the long diameter of the ellipse stretches nearly parallel to the tectonic axis of the mountain ranges in the district.

On account of its character, less resistant to erosion than the surrounding sedimentary rocks, it forms low hills along the Asa river valley. The eastern half of the mass is covered with brownish residual clay with a small quantity of quartz and feldspar mingled with minute flakes of biotite.

This intrusive mass has produced a contact alteration in the sedimentaries, especially in the limestone. It is of interest that the genesis of the main metallic ore deposits in the district is due to the metasomatic action of the hydrothermal solutions emanated from the consolidating magma which constructed the igneous mass.

It is highly probable that the igneous rocks in the district are intimately related to the large plutonic masses which are extensively

exposed in the Inner Zone of southwestern Japan and southern Korea. There being no direct evidence of the age of the intrusion of the dioritic mass in the district, it is generally believed that it may be referred to igneous activity of the late Mesozoic age.⁽¹⁾

The general relations of the geology of the southern part of the Province of Nagato are shown on the sketch map. (Pl. XII).

The greater part of the intrusive mass in the Ofuku district is composed of dioritic rock but mineralogically and structurally it varies slightly in different localities, ranging from tonalite to granite.

In general the central part of the mass is comparatively acid but in the marginal facies and in the dikes it becomes fine grained and even basic, decreasing in quartz, orthoclase and biotite and increasing in plagioclase and hornblende. Petrographically the mass may be roughly divided into the following three types such as tonalitic, granodioritic and granitic facies though it is impossible to draw a distinct line between them in the field on account of their gradual transition.

Tonalitic Facies

Tonalitic rock occupies the main part of the mass and is especially well exposed to the eastern side of the Ofuku and Sanjô mines. It is a medium grained quartz diorite containing hornblende and biotite as the essential ferromagnesian minerals.

The rock is darkish gray in colour owing to the mafic minerals and rather abundant iron ore. The mineral constituents of the rock can be readily determined with the naked eye.

Plagioclase shows almost characteristic polysynthetic twin lamellae and zonal structure. As determined by the immersion method, all plagioclases belong to the family of andesine with average composition close to $Ab_{65}An_{35}$ ($n_1=1.545$ and $n_2=1.550$ on 001).

Orthoclase never occurs in an idiomorphic form with whitish and pinkish colour. Occasionally it shows the Carlsbad twin. This mineral is always later in crystallization than plagioclase.

(1) Prof. T. KATO states "Certainly, most granitic rocks of Japan are post-Jurassic, but pre-Tertiary in age, since their erosion surfaces are covered by the early Tertiary coal-bearing series, as observed in the Eocene coal-fields in Kyushu and other districts." (The Periods of Igneous Activity in Japan with Special Reference to Metallogeny. The Second Pan-Pacific Science Congress. Vol. I, (1923), p. 810.)

Hornblende occurs usually as a short prismatic crystal and sometimes it shows twinning on 100. It is greenish in colour showing strong pleochroism, X = pale green, Y = brownish green, Z = dark greenish yellow, c:Z on 010 is 18° and refractive indices on 110 are $n_1=1.656$ and $n_2=1.669$. Many of the crystals exhibit an alteration due to the resorption phenomena in molten magma indicating the earliest crystallization among the essential constituents. (Pl. XIV, Fig. 6.) The secondary uraltite and chlorite occur as a decomposition product in the original crystals of hornblende.

Biotite occurs in small hexagonal flakes of 1 mm. diameter showing nearly perfect cleavage. It is sparingly sprinkled through the rock. It shows also strong pleochroism from straw-yellow to dark brown and the optical angle of the crystals is very small. Sometimes it is altered to chlorite. Index of refraction of the biotite is as follow: $\gamma = 1.651$.

Quartz is generally very scanty in quantity and a small percent of the mineral shows minute rounded crystal forms. It is the latest mineral to crystallize, filling the spaces between the interspaces of the plagioclase crystal accompanied by orthoclase. Sometimes fluid inclusion and negative crystals are abundant in xenomorphic quartz. There can be observed a small quantity of allanite showing a short prismatic crystal elongated parallel to b-axis. It is distinctly pleochroic, brown to dark brown, but sometimes it is almost dirty brown in colour, and shows an isotropic zone which may be due to the destructive action of the radioactive elements contained in the mineral.⁽¹⁾

Fine prismatic crystals of apatite and small grains of titanite, zircon, and magnetite occur relatively throughout the rock as accessory minerals. The zircon crystals enclosed in the biotite show a typical pleochroic halo.

A specimen of tonalite from Kanagahara near the Ofuku mine has been analysed by Mr. A. Kannari, of the Hokkaidô Imperial University with the result set forth in Table II, A. It should be compared with the analyses of the granodiorite from Ono⁽²⁾ Asa-gun, Nagato (Table II, B) and diorite from the western part of Sakurayama⁽³⁾, Miné-gun, Nagato (Table II, C). (See Pl. II).

(1) O. MÜGGE: Ueber isotrop gewordene Kristalle. Centralblatt f. Min. Geol. u. Palae., No. 24, 1922, p. 759.

(2) T. OGURA: Explanatory Text of the Geological Map of Japan, Sheet 263 (Yamaguchi) 1923, p. 29.

(3) T. SUZUKI: The Explanatory Text to the Yamaguchi Sheet, 1907, p. 71.

TABLE II.

	A		B		C	
	Percent.	Mol. Prop.	Percent.	Mol. Prop.	Percent.	Mol. Prop.
SiO ₂	64.40	1068	64.05	1062	57.50	954
TiO ₂	1.00	12.5	0.38	4.7	—	—
Al ₂ O ₃	18.44	180	20.42	200	16.98	166
Fe ₂ O ₃	0.03	—	1.92	12	9.95	62
FeO	4.00	56	2.96	41	—	—
MnO	0.18	3	1.81	26	0.68	10
MgO	1.64	41	0.75	19	4.03	100
CaO	4.75	85	3.67	65	7.56	135
Na ₂ O	3.10	50	1.40	23	1.03	17
K ₂ O	2.60	28	2.22	24	1.32	14
P ₂ O ₅	0.09	0.6	0.41	2.9	0.21	1.5
Ig. loss	0.65	—	0.21	—	1.38	—
Total	100.88		100.21		100.64	

Niggli Values

si	241	252	168
al	41	47.5	29.5
fm	22.5	26	41.5
c	19	15.5	23.5
alk	17.5	11	5.5
ti	2.82	1.11	—
p	0.14	0.69	0.26
k	0.36	0.51	0.45
mg	0.41	0.17	0.43
c/fm	0.84	0.60	0.57

(A) Tonalite, Kanagahara, near Ofuku mine, Miné-gun, Nagato.

(B) Granodiorite, Ono, Ono-mura, Asa-gun, Nagato.

(C) Pyroxene-diorite, western part of Sakura-yama, Mine-gun, Nagato.

Granodioritic Facies

Granodiorite occupies the southern part of the tonalite mass and is composed of nearly equal amounts of orthoclase and plagioclase, quartz with subordinate biotite and hornblende accompanied by apatite, zircon, magnetite and titanite as accessory minerals.

This rock can be distinguished from the tonalite by paying attention to the decrease of hornblende and plagioclase, and the increase of orthoclase and quartz. This is the transitional facies from tonalite to granite. (Pl. XV, Fig. 1).

Granitic Facies

At the southernmost and central part of the mass, the rock gradually becomes granitic in appearance which differs from the forementioned facies chiefly in containing more orthoclase and quartz. It is also characteristic that any crystal of the rock-forming minerals is much larger than those of the former. (Pl. XV, Fig. 2). The great kaolinization and sericitisation of feldspars in the rock indicate that a magma had been accompanied by a high percentage of volatile compounds, mainly water.

The analysis of biotite granite from Yonokida near Hirakunigi which was made by A. Kannari, is shown in Table III, A, where an analysis of biotite granite from Yamanaka⁽¹⁾ (B) Asa-gun, Nagato is tabulated for comparison.

TABLE III.

	A		B	
	Percent.	Mol. Prop.	Percent.	Mol. Prop.
SiO ₂	75.64	1254	72.57	1204
TiO ₂	0.05	1	0.21	2.6
Al ₂ O ₃	12.87	126	14.72	144
Fe ₂ O ₃	0.86	5	0.32	2
FeO	0.11	2	1.12	16
MnO	0.08	1	—	—
MgO	0.84	21	1.28	32
CaO	1.29	23	4.65	83
Na ₂ O	3.70	60	2.42	39
K ₂ O	4.22	45	1.76	19
P ₂ O ₅	tr.	—	0.75	5.3
Ig. loss	0.37	—	0.55	—
Total	100.03		100.35	

(1) T. OGURA: Explanatory Text of the Geological Map of Japan, Sheet 263 (Yamaguchi). 1923, p. 28.

Niggli Values

si	438	357
al	44	43
fm	12	15.5
c	8	24.5
alk	36	17
ti	0.35	0.77
p	—	1.57
k	0.43	0.33
mg	0.62	0.62
c/fm	0.66	1.58

- (A) Biotite granite, Yonokida near Ofuku mine, Miné-gun Nagata.
 (B) Biotite granite, Yamanaka, Matase-mura, Asa-gun, Nagato.

Dike Rocks

There are many dikes around the dioritic intrusive mass. These dikes are closely related geologically and lithologically to the main dioritic mass, indicating that they have been differentiated from the same magma. That is to say, at the last phase of the intrusion of the dioritic mass, the magma had differentiated locally into basic and siliceous portions forming the dikes of more basic porphyrites and siliceous aplites. It is noticeable that a few of them carried a large amount of mineralizer and metallic sulphides and deposited them in the limestone.

Porphyrite.—The dikes of porphyrite occur in several places in the district. Near the Sanjô mine a narrow dike penetrates the Palaeozoic chert and limestone giving them a slight contact effect. The dike is nearly 3 m. in breadth and 200 m. in length showing a strike of N. 45° W. and dip of a steep angle toward the south side. Owing to excessive decomposition, it is altered to a dark greenish gray rock of fine earthy texture in which only plagioclase lath can be recognized with the naked eye.

Under the microscope, it shows somewhat of a porphyritic structure consisting of phenocrysts of feldspars, and a groundmass of confused aggregate of plagioclase and chloritized biotite with rather abundant iron ore and apatite crystals as accessory minerals. Plagioclase crystals are commonly tabular in habit, and as it is almost saussuritised and kaolinized, accurate determination is not possible, but they are probably basic andesine, judging from the equal maximum symmetrical extinction angles. Albite twin is found abundantly.

The crystals of quartz, orthoclase and hornblende are very scanty in the section of the rock, and the groundmass is entirely free from glass. Small quantities of zircon, apatite, titanite and magnetite can be observed as accessories. (Pl. XV, Fig. 3).

In the western part of the district two small dikes of porphyrite penetrate the sandstone and the shale of the Mesozoic formation. Of the two dikes, one occurs by the road side near Tashiro,⁽¹⁾ the other is exposed at the meeting point of the Ominé⁽²⁾ road and Nishibata⁽³⁾ road in the village of Kuwahara.⁽⁴⁾

The former is about 10 m. thick with strike NE. and the latter is only 5 m. in thickness striking in a similar direction to the former. These dikes are closely similar to that at Sanjô, but locally they are decomposed, ranging in colour from whitish to grayish and characterized by a great quantity of quartz. Judging from the lithological character and geological relation, it is indubitable that these dikes are genetically related to the forementioned dioritic mass which crops out less than 3 km. eastward from the exposures of these dikes.

Though these dikes seem to have little concern with the formation of ore deposits, they are of great use in determining the limit of the geological age of the intrusive rocks in the district. For as already mentioned, these dikes caused the intense contact phenomena on the Mesozoic sedimentaries and metamorphosed them into hard compact hornfels, indicating that the igneous intrusion in the district took place in the post-Triassic age, perhaps in the late Mesozoic.⁽⁵⁾

At the Fukurei mine, there are two parallel dikes penetrating the Palaeozoic limestone and shale with strikes of near N. 10°E. and dips of high degree toward the west side (Fig. 9). The direction of their elongations is nearly coincident with that of the general strike of the sedimentaries near this mine. One of these dikes is about 20 m. wide though the length is undetermined. The other one is situated 20 m. west of the former and is less in width than the

(1) 田代 (2) 大嶺 (3) 西畑 (4) 桑原

(5) It has been suggested by T. Kato that the late Mesozoic period is one of the most significant for igneous activity and related metallizations in Japan and the neighbouring continent, and the phenomena in that period seem generally to have continued down to the Early Tertiary. (T. KATO: Geology and Ore Deposits of the Yanahara mining district, Prov. Mimasaka, Japan. Japanese Jour. Geol. Geogr., Vol. I, No. 3-4, (1922), p. 98).

other. The latter is entirely decomposed to a loose earthy material which is very difficult to distinguish from the shale around it.

The lithological characters of these dikes are megascopically almost similar to those near Sanjô and Tashiro, but under the microscope, they are seen to be composed essentially of plagioclase, quartz, diopside and titanite accompanied by a small quantity of accessory minerals such as apatite and magnetite. (Pl. XV, Fig. 4).

Accurately speaking, these dikes may be called by the name of diopside-titanite-quartz-porphyrite.

Plagioclase is tabular in habit showing commonly polysynthetic twinning according to the albite-law and occasionally pericline and Carlsbad types. As determined by the immersion method it belongs to the basic andesine $Ab_{52}An_{48}$ ($n_1=1552$ and $n_2=1556$ on 001). But sometimes the alteration has been produced intensely by the hydrothermal solutions, and some of the feldspar is kaolinized and sericitized.

It is most characteristic that these dikes contain a large quantity of crystals of diopside and sphene as essential minerals. The occurrence of these minerals may be explained by the differentiation of syntectic action, which is due to the endomorphic contact phenomena between calcareous sedimentaries and diorite porphyrite owing to the direct contact of these rocks. To speak more precisely these two silicate minerals were produced in consequence of the combination of excessive iron, manganese and titanium in siliceous magma, with a high percent of lime which was largely assimilated from the neighbouring calcareous rocks.⁽¹⁾

(1) On the presence of a considerable quantity of lime bearing silicates such as diopside, hedenbergite and titanite in the some phases of igneous masses, granite gneiss and pegmatite, in Western Massachusetts, B. K. Emerson and P. Eskola, have supposed it to be explained in the same way. The latter author has referred to the fact that assimilation does not require very high temperatures being a very common phenomenon in granite, pegmatite cutting limestone. (B. K. EMERSON: *Geology of Massachusetts and Rhode Island*. U. S. G. S., Bull. 597 (1917), PENTTY ESKOLA, On the contact phenomena between gneiss and limestone in Western Massachusetts. *Jour. Geol.* Vol. XXX, No. 4, (1922), p. 265-294.) The similar facts in the granitic and dioritic rocks at Tennberg, Sweden, the Henderson mine of Usakos in South Africa and Traversella in Italy, have respectively been described by H. von Eckermann, M. Brinkmann and W. Q. Kennedy. (ECKERMANN: *The Rocks and Contact Minerals of Tennberg*. *Geol. Fören Stockholm Förh.* Band 45, No. 355, 1923, p. 530, M. BRINKMANN, Die kontakt-peumatolytische Kupferlagerstätte der Hendersongrube bei Usakos in Deutsche-Südwestafrika. *Zeit. f. prak. Geol.* XXXII Jg, 1924 p. 35, and W. Q. KENNEDY: *The Igneous Rocks, Pyrometasomatism and Ore Deposition at Traversella, Piedmont, Italy*. *Schweiz. Min. Petr. Mitt.* Bd. XI, Heft 1. 1931, p. 96).

A chemical analysis of the porphyrite of Sanjô which was made by A. Kannari, is set out in Table IV (A) and is there compared with analyses of porphyrites from Arakawa⁽¹⁾ (B) and Matsugase⁽²⁾ (C) and quartz-hyperite from Kurogoro⁽³⁾ (D).

TABLE IV.

	A		B		C		D	
	Percent.	Mol. Prop.						
SiO ₂	65.79	1091	58.10	964	60.31	1000	60.53	1004
TiO ₂	0.15	2	1.73	21.6	0.06	0.7	0.31	3.9
Al ₂ O ₃	16.13	158	16.64	163	16.15	158	19.78	194
Fe ₂ O ₃	0.48	3	8.13	51	8.83	55	1.88	12
FeO	4.02	56	—	—	—	—	6.72	94
MnO	0.10	1	0.54	8	0.32	5	0.45	6
MgO	1.33	33	0.48	12	2.19	54	1.63	42
CaO	4.42	79	4.74	85	5.98	107	3.84	69
Na ₂ O	3.59	58	3.02	49	2.28	37	1.45	23
K ₂ O	3.43	36	2.32	25	1.88	20	0.79	8
P ₂ O ₅	tr	—	0.26	1.8	0.23	1.6	0.96	6.8
Ig. loss	1.01	—	3.64	—	0.87	—	1.40	—
Total	100.45		99.60		99.10		99.75	

Niggli Values

si	256	217	203	219
al	37	37	32	42
fm	22.5	27.5	34.5	36
c	18.5	19	22	15
alk	22	16.5	11.5	7
ti	0.45	4.86	0.14	0.85
p	—	0.41	0.33	1.48
k	0.38	0.34	0.35	0.26
mg	0.32	0.10	0.32	0.25
c/fm	—	0.69	0.64	0.42

(A) Prophyrite, Sanjô mine, Ofuku mura, Miné-gun, Nagato.

(B) Porphyrite, Arakawa, Omine mura, Miné-gun, Nagato.

(C) Pyroxene porphyrite, Matsugase, Asa-gun, Nagato.

(D) Quartz hyperite, Kurogorô, Yoshibe mura, Asa-gun, Nagato.

(1) T. SUZUKI: Explanatory Text of the Yamaguchi Sheet, 1907, p. 78.

(2) Ibid. p. 77.

(3) T. OGURA: Explanatory Text of the Geological Map of Japan, Sheet 263 (Yamaguchi) 1923, p. 29.

Aplitic Leucocrate.—In the west part of the Ofuku mine, two small dikes occur along the fault valley, giving a slight contact effect to the Palaeozoic formation. They are of light grayish rock and apparently composed of fine equigranular aggregate of quartz and feldspar, being very poor in mafic minerals. Under the microscope, they are found to be formed essentially of orthoclase and quartz grain with small amounts of plagioclase ($Ab_{70} An_{30}$), biotite, apatite and garnet as accessory minerals. The feldspar is commonly hypidiomorphic, showing Carlsbad twins, and the quartz is more idiomorphic and very fresh. (Pl. XV, Fig. 5.)

It is noticeable that these dikes crystallized out from a residual solution⁽¹⁾ as the latest and most acid phase of the dioritic mass by a process of siliceous differentiation. It may occasionally be observed that these acid dikes pass gradually into a quartz vein which usually accompanies with various metallic ores. The intimate relation between them has been pointed out by many authors.⁽²⁾

IV. THE ORE DEPOSITS

Many ore deposits in the district have occurred in the sedimentaries, especially in limestone, at or near the contact with the intrusive rocks and along fissures at considerable distances from the contact. As shown by the annexed geological map, they arrange around the diorite mass in an elliptical shape.

The formation of the ore deposits is clearly due to the contact phenomena between sedimentaries and metamorphosing solutions expelled from the consolidating igneous intrusives. The forms of the contact metamorphic ore deposits and the variations of the characters of the mineral compositions, are due to the difference in the physical conditions and the chemical characters of the solutions during the period of deposition. Copper, silver and iron ores are the principal products in the district. A small amount of other metallic ores

(1) A. HARKER: *Natural History of Igneous Rocks*. (1909), p. 295.

(2) J. BARRELL: *Geology of the Marysville Mining District, Montana*. U. S. G. S., Prof. Paper, 57, (1907), W. LINDGREN: *The Characters and Genesis of Certain Contact Deposits*. A. T. M. E. Trans., Vol. 31, (1903), pp. 242-244; T. W. SPURR: *Geology of the Yukon Gold District, Alaska*, U. S. G. S., 18th. Ann. Rept., (1898), p. 311, J. E. SPURR: *A Consideration of Igneous Rocks and their Segregation or Differentiation as Related to the Occurrence of Ores*. A. T. M. E., Trans. Vol. 33, (1902) pp. 288-340; J. E. SPURR, G. H. GARREY and C. H. FENNER: *Study of a Contact Metamorphic Ore Deposit. The Dolores Mine, at Matchuala, S. L. P., Mexico*. Econ. Geol., Vol. VII, (1912), p. 445, 473, etc.

such as lead, molybdenum, tungsten and gold, are also accompanied by the copper ores, but they have not been found in commercial quantities in the district.

Many silicate minerals which are always associated with the metallic ores, occur not only adjacent to the very contact of the intrusive mass but in many places far away from the igneous bodies. The relative proportion of these metallic ores and silicate minerals varies widely at different localities.

According to the geological relations, the following three types of ore deposits have been recognized in the district, though it is certain that these deposits have originated from the same magma.

(1) The ore deposits developed in the lenticular limestones which are intercalated in the chert layers.⁽¹⁾ Main ore bodies in the Ofuku, Sanjô and Nagawo⁽²⁾ mines belong to this type.

(2) The ore deposits developed in the limestone mass which composes the thick plateau land. The Fukurei,⁽³⁾ Miné,⁽⁴⁾ and Maruta⁽⁵⁾ deposits are included in this type.

(3) The ore deposits occupied the fissures along the fault plane between the limestone and sandstone. The Takara⁽⁶⁾ mine and a part of the Ofuku deposit are representative of this type.

(A) The Ofuku Deposits

General Features

The Ofuku mine⁽⁷⁾ is located on the western side of the dioritic mass, and the main body of the deposits shows a large irregular long tabular form, occurring in the lenticular limestones intercalated

(1) The ore deposits of the first type are the greatest in size and from an economical point of view are the most important in the district.

(2) 長尾 (3) 福嶺 (4) 嶺 (5) 丸太 (6) 寶

(7) The geology and ore deposits of the Ofuku mine have been described by several authors such as T. Kato, T. Hirabayashi, T. Ogura and J. T. Chang. (T. KATO, Mineralization in the Contact Metamorphic Ore Deposits of the Ofuku Mine, rev. Nagato, Japan. Jour. Geol. Soc. Tokyo, Vol. XX, (1913), pp. 13-32. T. HIRABAYASHI, The Ofuku Mine. (In Japanese). The Trend of the Japanese Mining Industry, Publication from the Bureau of Mines. (1916) pp. 406-408. T. OGURA, The Ore Deposits in the Environ of the Ofuku Mine. (In Japanese). Imp. Geol. Surv. Japan, Rept. No. 82; (1921), pp. 19-35. J. T. CHANG, The Geology and Ore Deposits of the Ofuku District. Manuscript (1922)).

in chert. The length of the body is about 150 m., and the lowest part is about 100 m. vertically below the outcrop. The part of the main body having the maximum sectional area is 12 m. by 15 m. It is clear that the ore deposits of the mine are due to the metasomatism of the lenticular limestone in chert on account of the contact effect of the tonalite mass, though it is impossible to find the immediate contact of these two rocks in the field.

In other words, the ore bodies in the mine have served as channels for the escape of a portion of the hydrothermal emanation

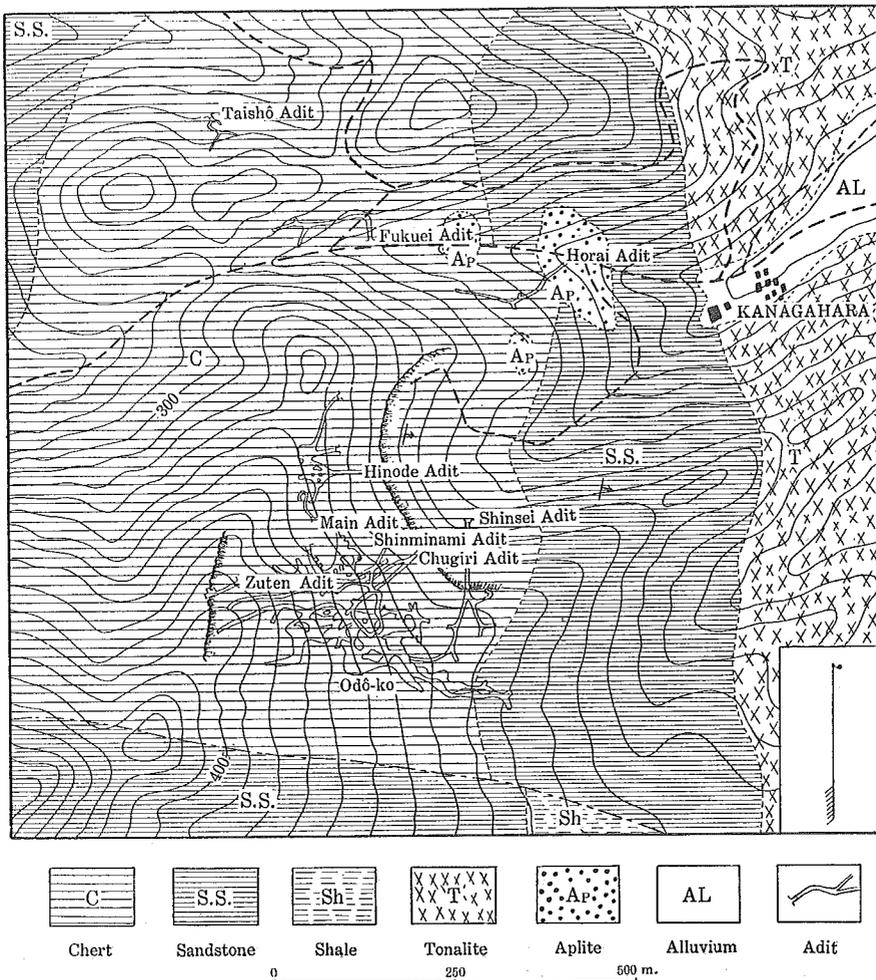


Fig. 2. Geological map of the Ofuku mine showing under-ground working.

from a more deeply situated igneous mass. The hydrothermal solution may have ascended to a considerable distance from the main mass of the intrusives owing to its great fluidity. (See Fig. 6).

The sketch map of the geology and adits of the Ofuku mine are shown in Fig. 2.⁽¹⁾

In general the ore deposits have the strikes of N. 20-30° E. dipping to the east 30° to 70°, showing subparallel to the layers of the country rocks. As shown in the figure, the deposits are mainly cut at five levels, being combined with an inclined shaft along the direction of the main body.

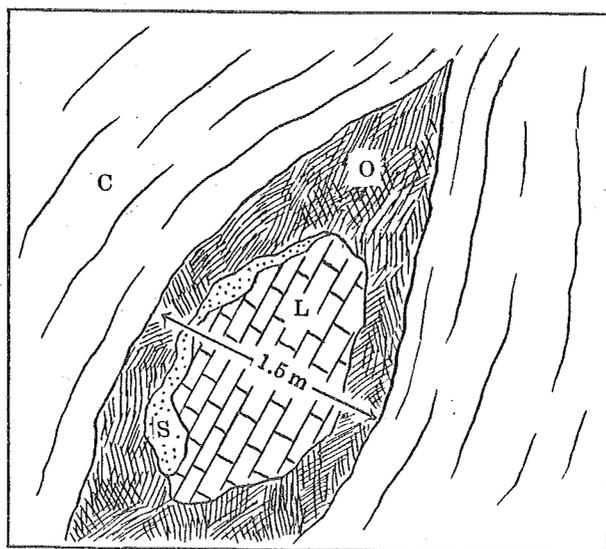


Fig. 3. Small ore mass which replaced the thin lenticular limestone at the entrance of the Honkô Adit, C=Chert, L=Residual limestone, O=Ore mass, S=Skarn.

Zutenkô,⁽²⁾ the uppermost adit, is situated near the top of the Ofuku mountain. In the adit a large quantity of spongy brown iron oxide and green copper oxide can be observed. They are undoubtedly gossan derived from the sulphide ores of iron and copper.

(1) The map of mine working has been furnished by the operators of the mine, the geological distribution having been added by the writer.

(2) 頭天坑

Three parallel adits in the middle part, Honkô, Shimminamikô and Chugirikô, are all connected with the Ôdôkô adit which runs through the most important ore mass in the mine.

The Honkô⁽¹⁾ adit is situated about 40 m. beneath the Zutenkô adit, but now the greater part of the adit is abandoned, and no ore is produced. A small ore mass can be observed at the entrance of the Honkô adit, though it has no economical value. (Fig. 2).

The Shimminamikô⁽²⁾ adit and the Chugiri⁽³⁾ adit which were worked on the upper part of the Ôdôkô,⁽⁴⁾ lead to the Honkô adit. Ôdôkô is the most important and largest adit in the mine. The ore mass which was penetrated by it was composed of large quantities of chalcopyrite and some oxidized ores. This irregular mass was elongated in the direction of nearly N. 20°E. and has a dip of 65° towards the east. The maximum diameter of the mass was about 15 m. but at present the great mass is almost exhausted and only a small quantity of chalcopyrite which fills up the cracks of chert is sought for. At the foot wall of this adit, residual succharoidal limestone can be observed.

The lowermost adit, Shinseikô,⁽⁵⁾ is the longest one in the mine and the ore mass is situated about 30 m. south from the adit. This ore mass is clearly a lower continuance of the principal ore body of Ôdôkô. The ore mass is composed chiefly of chalcopyrite with small quantities of pyrite, zincblende and galena, but the oxidized ore becomes less and less in quantity.

Isolated ore masses which have more or less economical value, can be observed in the northern part of the mine. These ore masses were worked at the Taishôkô⁽⁶⁾ adit and the Hôraikô⁽⁷⁾ adit on a very small scale. These two openings are now abandoned. The former was worked by open air cutting for the purpose of getting only the outcrop of the oxidized iron ore, and its level nearly corresponds to that of the Zutenkô adit. In the latter adit, Hôraikô, a small aplitic dike penetrates the chert and lenticular limestone giving some metamorphism to these sedimentaries. The small mass of limestone was replaced by the metallic ores and silicate skarn mass,

(1) 本坑 (2) 新南坑 (3) 中切坑 (4) 大洞坑 (5) 新盛坑 (6) 大正坑
(7) 寶來坑

In general, the principal primary ores⁽¹⁾ found in the Ofuku mine are, arranged in order of abundance, as follows: Chalcopyrite, pyrite, pyrrhotite, arsenopyrite, molybdenite, sphalerite, galena and scheelite. The chalcopyrite is the chief source of copper in the mine, but some of the other sulphides are almost negligible from an economical point of view. These metallic ores are always associated with a considerable amount of the typical silicate minerals such as wollastonite, vesuvianite, garnet, hedenbergite, diopside, epidote and are enriched by the oxidation of sulphides and the solutions of copper in the zone of weathering. The secondary minerals found in the enriched zones are as follows: limonite, cuprite, malachite, azurite, chrysocolla, covellite, bornite, smithsonite, chalcocite and others.

There have been found no argent ores in the deposits except small quantities of native silver flakes. The analytical content of silver may be inclosed in galena.

The above mentioned ores of the deposits show rather marked differences in character at different depths. The main ore body in the mine may be roughly divided into three zones; upper, middle and lower. The general distribution of the ore minerals in these zones is as follows.

Upper zone (Zutenkô).—This zone is composed chiefly of oxide and carbonate of copper and iron associated with small quantities of molybdenite and scheelite which has partly changed to copper tungstate. Limonite is the most prominent ore in the zone.

(1) The production of copper and copper ore from the Ofuku mine was as follows:

	Copper	Ore	(Ag ‰)	(Cu ‰)
1911	41,566 Pounds	—	—	—
1912	96,560 "	—	—	—
1913	114,158 "	—	—	—
1914	132,599 "	—	—	—
1915	155,729 "	—	—	—
1916	213,746 "	—	—	—
1917	143,746 "	2,181 Tons	1.25	1.85
1918	135,636 "	3,563 "	1.20	1.70
1919	160,187 "	2,157 "	1.10	1.65
1920	36,700 "	1,767 "	1.20	2.75
1921	—	1,953 "	1.90	3.20
1922	—	1,914 "	1.93	3.72
1923	—	1,674 "	2.03	3.50
1924	—	1,855 "	1.80	3.48
1925	—	2,271 "	1.45	3.10
1926	—	2,105 "	1.44	3.55
1927	—	1,869 "	1.64	3.01
1928	—	1,496 "	2.04	3.93
1929	—	1,675 "	1.66	3.06
1930	—	1,262 "	2.13	4.33

Middle zone (Ôdôkô).—It consists of a great mass of chalcopyrite and other sulphide mingled with a large quantity of the secondary enriched ores of copper, iron and zincblende.

Lower zone (Shinsekô).—This horizon is formed with chalcopyrite and other sulphide, but the secondary mineral is very scanty. A small amount of zincblende and galena is characteristic in the zone. It is possible that the deeper zone may contain a greater quantity of zincblende and galena than of sulphides of iron and copper.

It is important to determine the extension of the secondary alteration in ore bodies. In the Ofuku mine, the ore bodies have not yet reached the fixed water table and oxidized products are widely distributed, not only in the upper horizon but in the lowermost level which is about 100 m. or more vertically below the outcrops. The more mature topography makes conditions more favorable for oxidations and enrichment to take place.

In the lower part, however, the interior of the ore mass generally shows fresh minerals on account of the fact that oxidation extends only along the small fissures. The oxidation of the minerals is due to the descending meteoric waters⁽¹⁾ through each fissure, and these meteoric waters dissolve considerable quantities of cupric or ferric sulphate and free oxygen and carry them downwards. When the waters are partly evaporated, the many secondary minerals of copper and iron precipitate in cavities or druses of the wall rocks.

Alteration products in the mine are generally composed of formations of oxides and carbonates with small quantities of secondary sulphides. The following minerals are the secondary products occurring in the oxidized zone of the mine; limonite, cuprite, malachite, azurite, chrysocolla, chalcantite, smithsonite, covellite, bornite, chalcocite, native silver and copper, kaolinite and secondary tungsten mineral.

(1) On the characters of descending water A. C. Spencer concluded that when oxygen bearing waters reach the upper part of the mass of sulphide bearing rock the consumption of dissolved oxygen begins at once, and before the waters can progress downward for any considerable distance all this free oxygen is used up in decomposing the sulphides. Within a short distance also, ferric sulphate is largely reduced to ferrous sulphate. So long as free oxygen is present the decomposition of chalcocite will progress until no sulphuric acid remains uncombined. It should be added that there is little concentration in any solution containing cupric and ferrous sulphates. (U. S. G. S. Prof. Paper, No. 96, (1917), p. 83).

Contact Metamorphism of the Carbonate Rocks

As has already been mentioned the origin of the various contact rocks and ore bodies in the district was due to a process of pyrometasomatism of the limestone by the highly heated solutions which were expelled from the consolidating dioritic magma.

The general sequence of the crystallization of the primary minerals in the contact zones is closely related to the gradual cooling of the mineralizing solution on account of conduction and transformation into cooler rock and other causes. The sequence of mineral deposition indicates the physical and chemical changes that have taken place in the character of the mineralizing solutions.

Judging from the occurrence of the primary minerals, the succession of the epochs of mineralization in the contact zone can roughly be determined though it is impossible to draw sharp lines between them.

When the diorite mass intruded into the sedimentaries the former gave an intense deformation to the latter, especially to the limestone layers forming saccharoidal aggregation of calcite grains in consequence of the recrystallization of the original rock.

The pyrometamorphic rocks between the saccharoidal limestone and ore body may be classified mainly into three zonal divisions according to the characteristic mineral components; wollastonite rock, garnet rock and pyroxene rock.

The white zone of wollastonite deposited in direct contact with the saccharoidal limestone at the first stage of the mineralization from the metamorphosing solution. Some fine crystals of vesuvianite scattered in the wollastonitefels indicate that the mineral is also an early product of mineralization in the deposits. The vesuvianite has been crystallized out earlier than the garnet and other main skarn minerals and this seems generally to be the normal sequence in the similar contact zone at other localities. The main skarn mass which is composed chiefly of garnet and pyroxene, containing a relatively small amount of epidote, was formed almost contemporaneously with the wollastonite rock. It has generally been recognized⁽¹⁾ that a vesuvia-

(1) C. E. TILLEY: Australasian Antarctic Expedition Scientific Reports. Ser. A. Vol. III, part II (1923) p. 244. H. von ECKERMANN: The Rocks and Contact Minerals of Tennberg. Geol. Föhr. Bd. 45 (1923), p. 501.

nite and an epidote are thermally separated by a garnet and the paragenesis of epidote and vesuvianite is unstable while vesuvianite-garnet and garnet-epidote fields are of common occurrence.

At the last moment of the mineralization of the main skarn, many metallic ores began to crystallize out from the solution. The metallic minerals show also a notable change in passing from one type to another. For example, at high temperatures copper and iron were in part deposited while the zinc and lead remained in solution, and as the temperature decreased, the zincblende and galena were deposited as well as the former ones.

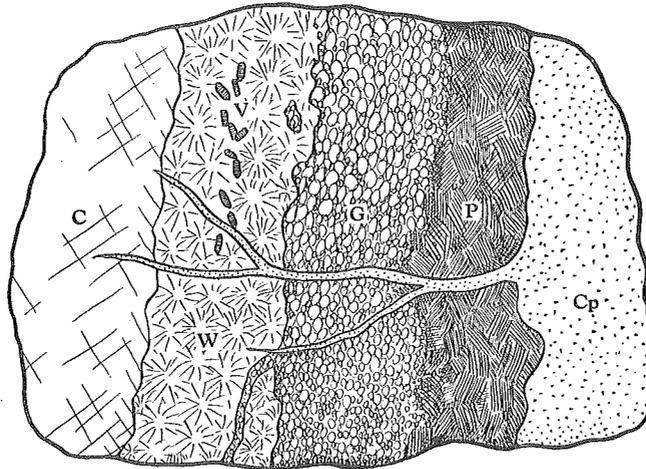


Fig. 4. Diagrammatic sketch, showing relations between various minerals in the Ofuku deposits.

C = Calcite, W = Wollastonite, V = Vesuvianite,
G = Garnet, P = Pyroxene, Cp = Chalcopyrite.

In the following Table the chemical analyses of the wollastonite rock (A) garnet rock (B) and the diopside rock containing accessory garnet (C) from the Shinsei-adit of the Ofuku mine, are given. All analyses were newly made by A. Kannari, of the Hokkaido Imperial University.

TABLE V.

	A		B		C	
	Percent.	Mol. Prop.	Percent.	Mol. Prop.	Percent.	Mol. Prop.
SiO ₂	49.69	824	38.11	632	45.87	761
TiO ₂	—	—	2.30	29	0.03	—
Al ₂ O ₃	1.50	19	4.45	44	2.34	23
Fe ₂ O ₃	—	—	22.31	140	5.62	35
FeO	7.90	110	0.79	11	18.54	258
MnO	1.67	41	0.23	3	0.89	22
MgO	0.15	4	0.49	12	1.99	49
CaO	36.79	656	30.20	538	21.64	385
Na ₂ O	0.91	15	0.89	14	1.18	19
K ₂ O	0.21	2	0.27	3	0.19	2
P ₂ O ₅	tr.	—	0.08	1	tr.	—
CO ₂	1.52	35	—	—	1.40	32
Ig. loss	0.03	—	—	—	0.05	—
Total	100.37		100.12		100.53	

Niggli Values

si	95.3	71.7	99.5
al	2	5	3
fm	18.5	33.5	47.5
c	77.5	59.5	47
alk	2	2	2.5
ti	—	3.3	—
p	—	—	—
co ₂	3.7	—	4
k	0.12	0.17	0.10
mg	0.03	0.04	0.13
c/fm	4.18	1.77	0.99

(A) Wollastonite rock, Shinseikô-Adit, Ofuku mine, Nagato.

(B) Andradite rock, Shinseikô-Adit, Ofuku mine, Nagato.

(C) Andradite-bearing diopside rock, Shinseikô-Adit, Ofuku mine, Nagato.

From the analyses it is easy to recognize the chief difference among them. The amount of al and alk is practically the same in each rock, but the wollastonite rock shows an extremely high content of c and a low content of fm compared with the analysis of diopside rock. It is noticeable that c and fm contents in the garnet rock

show respectively a just mean value between the wollastonite rock and diopside rock.

In Fig. 5 the calculated values of three contact rocks in question have been plotted. If the molecular values of garnet from Kamihogi and Yoboshi (Table VI), and of pyroxene from Sasagatani (Table VII) are included in the same diagram, we can find that there are certain distinct regularities in the distribution of each. The garnet rock shows a remarkable degree of purity, the analysis corresponding very closely with the analysis of the actual mineral from Kamihogi.

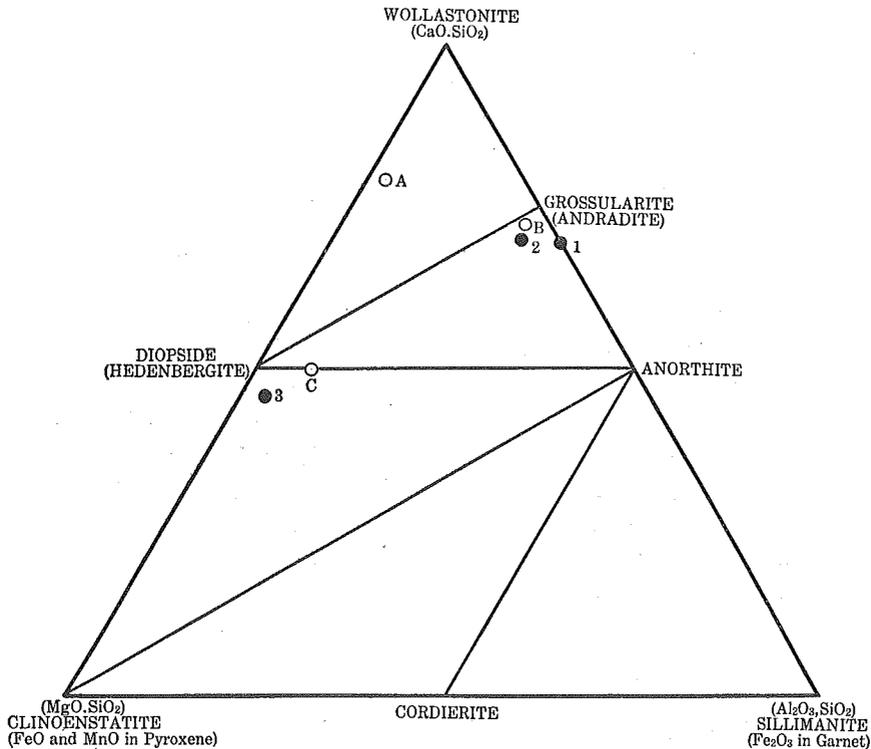


Fig. 5. Diagram of the system $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$, in which there is isomorphous replacement of MgO by FeO and MnO , and of Al_2O_3 by Fe_2O_3 . A Wollastonite rock (Ofuku Mine), B Andradite rock (Ofuku Mine), C Andradite-bearing diopside rock (Ofuku Mine), 1 Andradite (Yoboshi Mine), 2 Andradite (Shimohogi Mine), 3 Hedenbergite (Sasagatani Mine).

Mineralogical Composition of the Deposits. Gangue Minerals

Wollastonite.—This meta-silicate of calcium is a prominent gangue mineral and is one of the principal constituents of the contact zone

in the Ofuku mine. Usually this mineral develops along the immediate contacts of limestone and the cracks in chert. (Pl. XIV, Fig. 5, Pl. XIX, Fig. 2). It occurs as an aggregate of white fibrous clusters with radial structure, essentially forming a wollastonite-fels.

Under the microscope, it is colourless and the double refraction and the index of refraction are generally high. The two principal cleavages along 100 and 001 and the direction of elongation are perpendicular to the plane of symmetry. (Pl. XV, Fig. 6, Pl. XVI, Figs. 1-2).

The wollastonitefels is fresh and usually free from other gangue minerals, though it is rendered to be slightly impure by the presence of small quantities of brownish vesuvianite, garnet and greenish diopside. Sometimes the wollastonite-fels is transversed by the veinlets of garnet, hedenbergite or sulphide minerals and the interspaces between the prismatic crystals of the wollastonite clusters are filled with quartz with inclusions of diopside grains.

The mode of occurrence clearly shows that the wollastonite has been formed at the earliest stage of the contact metamorphism, indicating it did actually mineralize within a high temperature. Occasionally a small quantity of diopside and garnet is embedded in wollastonite showing that the crystallization of wollastonite has continued to the earlier stage of crystallization of the main skarn.

Vesuvianite.—Small masses of vesuvianite, minute prismatic crystals, 1 mm. in length, occur in the form of a veinlet of irregular aggregation in the wollastonite-fels. The mineral is brownish in colour with a vitreous luster megascopically, but under the microscope it is nearly colourless or very light brownish. It shows straight extinction and the characters of the mineral and zone are negative. In the coloured crystal, sometimes very slight pleochroism can be observed. (Pl. XVI, Fig. 1).

Garnet.—Next to wollastonite, garnet is also an important skarn mineral in the mine and it is present in considerable amounts throughout the district. It occurs in coarse grained aggregates of rhombic dodecahedral crystal, ranging in size from a few millimeters to one centimeter, and is usually closely associated with diopside, quartz and calcite. Garnet-fels occurs with a sharply defined border towards both side of the diopside- and wollastonite-fels. Sometimes it occurs as narrow veinlets traversing through wollastonite-fels. (Pl. XX, Fig. 1). Though variable in colour, from reddish brown to greenish brown, it is probably all referable to the lime iron variety, *andradite*.

Under the microscope, the garnet crystal usually shows optical anomaly,⁽¹⁾ showing distinct weak birefringence and zonal structure indicating the gradual changes in composition during the growth of the crystals. (Pl. XVI, Figs. 2-4). The outer zones are always darker in colour than the inner part showing that they are probably richer in iron. Occasionally the crystal is divided into three or more segments. As already mentioned the veinlets of garnet penetrate the wollastonite-fels, but on the other hand a small quantity of garnet grains are enclosed in the wollastonite crystals. Minute veinlets of calcite and quartz partly transverse the garnet skarn. It is clear that the stage of crystallization of garnet is almost similar to that of hedenbergite.

The chemical composition of garnet itself from this district is not known, but judging from the before-cited analysis of the garnet-rock, it seems to show entirely similar composition to those of Yoboshi and Shimohogi which had been recorded by T. Wada⁽²⁾ and T. Kato.⁽³⁾ The analyses of the garnets from these mines are set forth below for reference.

TABLE VI.

	A		B	
	Percent.	Mol. Prop.	Percent.	Mol. Prop.
SiO ₂	35.70	592	36.10	599
Al ₂ O ₃	3.45	34	—	—
Fe ₂ O ₃	26.09	163	35.27	221
MnO	0.22	3	—	—
MgO	1.43	36	—	—
CaO	31.20	556	28.00	499
Na ₂ O	0.22	4	—	—
K ₂ O	0.18	2	—	—
Ig. loss	1.65	—	—	—
Total	100.14		99.37	

(A) Andradite, Shimohogi, Toyoura-gun, Nagato.

(B) Andradite, Yoboshi near Ōda, Miné-gun, Nagato.

(1) W. Q. Kennedy stated that optical anomalies of the garnets in the Traversella rock were only observed in one case where they indicate the rhombic dodecahedron (Schweiz. Min. Petr. Mitt. Bd. XI. Heft. 1. (1931). p. 102).

(2) T. WADA: Minerals of Japan. (1904) p. 111.

(3) T. KATO: The Ore Deposits in the Environs of Hananoyama near the Town of Ōda, Province of Nagato, Japan, Jour. Meiji Coll. Tech., Vol. I, No. 1, (1916), p. 26.

These analyses show that ferric iron predominates greatly over alumina indicating that the garnets are andradite with only a slight admixture of grossularite molecule.

Diopside.—It occurs as one of prominent gangue minerals, usually associated with garnet skarn, and is occasionally embedded in wollastonite masses. The amount of diopside crystals is less than that of garnet but sometimes it forms granular diopside-fels. This skarn mass is compact and dark greenish in colour and is penetrated occasionally by veinlets of quartz, calcite and some sulphide ores.

Microscopically diopside skarn is composed of an aggregate of fine crystals, 0.03–0.1 mm. in length and partly intermingled with a small quantity of tremolite and a few flakes of biotite with pleochroism from greenish yellow to yellowish brown.

The diopside shows a short prismatic habit with a colour range from nearly colourless to pale greenish. The cleavage is nearly perfect and occasionally a basal section is observed. The double refraction is rather high and the maximum extinction angle $c:Z$ on 010 is about 39° . The indices of refraction of the mineral in cleavage flakes were approximately determined: $n_1 = 1.679$ and $n_2 = 1.698$ on 110, from which results the composition $Di_{85}Hd_{15}$. Generally the interspaces of the diopside crystals, are filled up by quartz and calcite and are often penetrated by veinlet of garnet though sometimes diopsides fill up the interspaces of the wollastonite aggregate. Greenish chlorite flakes with weak pleochroism, are also recognized in the diopside skarn. These flakes are probably the secondary alteration products of the biotite and diopside. (Pl. XVI, Fig. 6).

The crystallization of diopside seems to have taken place later than that of wollastonite but little earlier than that of some of the garnet, calcite and quartz.

Hedenbergite.—This mineral occurs as minute prismatic crystals mingled with the garnet and diopside crystals, forming a radial aggregation of a dark greenish colour. Though it is nowhere present in great quantities, it is widely distributed through the deposits.

Under the microscope, it shows long and short prismatic crystals with perfect cleavage, and an eight-sided basal section also can be recognized. It shows a light green colour and a rather strong double refraction. The maximum oblique extinction angle of the prism is nearly 44° and optically positive. It has $n_1 = 1.711$, and $n_2 = 1.727$ on 110, conforming to the composition $Hd_{55}Di_{45}$. (Pl. XVI, Fig. 5).

This ferrous type of diopside probably began to be mineralized a little earlier than the garnet. The local intimate mixture and zonal arrangement of the garnet and hedenbergite crystals indicate that cessation of the crystallization of the latter mineral was at nearly the same time as that of the former. It is common that fine prismatic crystals are enclosed in calcite and quartz as in the case of diopside and garnet. It has been generally recognized that a hedenbergite appears to have been pneumatolytically formed by the action of volatile constituents.⁽¹⁾

As the chemical composition of any pyroxene from the district is unknown, two analyses of the pyroxene of the similar contact metamorphic deposit of Sasagatani⁽²⁾ and Yoboshi⁽³⁾ are shown below for comparison.

TABLE VII.

	A		B	
	Percent.	Mol. Prop.	Percent.	Mol. Prop.
SiO ₂	48.40	803	48.58	806
Al ₂ O ₃	3.66	36	—	—
Fe ₂ O ₃	—	—	29.59	185
FeO	20.81	290	—	—
MnO	4.65	65	—	—
MgO	1.20	30	—	—
CaO	22.20	396	22.21	396
Total	100.92		100.38	

(A) Hedenbergite, Sasagatani Mine, Iwami.

(B) Hedenbergite, Yoboshi Mine, Nagato.

(1) H. von ECKERMANN: The Rocks and Contact Minerals of the Mansjo Mountains. Geol. Fören Forh. (1922), and The Rocks and Contact Minerals of Tennberg. Geol. Fören Forh. (1923). V. M. GOLDSCHMIDT: Die Gesetze der Gesteinsmetamorphose mit Beispielen aus der Geologie des Sudl. Norwegens. Vidensk. Skrift. I. Math naturw. Kl. (1912), Nr. 22. M. BRINKMANN: Die kontakt pneumatolytische Kupferlagerstätte der Hendersongrube bei Usakos in Deutsch-Südwestafrika. Zeitschrift f. prakt. Geol. 32 Jg. (1924).

(2) N. FUKUCHI: Mineral Paragenesis in the Contact Metamorphic Ore Deposits, found in Japan. Beiträge zur Mineralogie von Japan, Herausgeg. von T. WADA: Nr. 3 (1907), p. 92.

(3) T. KATO: The Ore Deposits in the Environs of Hananoyama near the Town of Ôda, Province of Nagato, Japan. Jour. Meiji Coll. Tech., Vol. I, No. 1, (1916), p. 25.

Biotite.—As already mentioned, this mineral occurs in the diopside skarn and hornfels which are due to the effect of contact phenomena between sandstone and intrusive rocks. In both cases it is small brownish flake showing the characteristic pleochroism, brownish yellow parallel to the cleavage and dark brown perpendicular to it. (Pl. XIV, Fig. 4, and Pl. XVII, Fig. 2). Considering the occurrence, the formation of metasomatic biotite⁽¹⁾ denotes that high temperature and the crystallization of the mineral may have taken place at an early stage in the metamorphism in the district.

Epidote.—This mineral is of frequent occurrence associated with the other skarn minerals, but it is not so widely distributed as most of the other minerals, being always in small amount. The epidote crystal is usually very small and can scarcely be observed microscopically.

Under the microscope it shows the ordinary prismatic habit parallel to the b-axis and sometimes twinned along the orthopinacoid. (Pl. XVII, Fig. 5). Where associated with garnet and diopside skarn, the epidote fills up the interspaces of these minerals indicating that the mineral has crystallized out at a comparatively low temperature. In other words, it seems to be the final hydrotogenic reaction product in the contact zone as transformation of primary minerals in the course of skarn formation.

Lievrite.—This iron black mineral is interesting as a typical product of a contact metamorphic origin as is stated by W. Lindgren.⁽²⁾ It occurs as imperfect orthorhombic prisms elongated parallel to c-axis associated with calcite and garnet, but the amount is very small in the deposits. (Pl. XVII, Fig. 3).

Under the microscope it is feebly translucent and often shows a very slight pleochroism from dark brown to black. Judging from the occurrence of the mineral it seems clearly to have crystallized out in the earlier stage of the main skarn. (Pl. XVII, Fig. 1) The occurrence of the same mineral is already known in the similar contact metamorphic deposit of Zomeki which is situated 40 km. north-east of the Ofuku mine.

The analysis of lievrite from Zomeki⁽³⁾ is set out in table below.

(1) W. LINDGREN: Metasomatic Process in Fissure Veins. A. I. M. E. Trans., Vol. XXX (1901), p. 645.

(2) W. LINDGREN: The Character and Genesis of Certain Contact Deposit. A. I. M. E., Trans., Vol. XXXI, (1902), p. 227.

(3) Jour. Geol. Soc. Tokyo, Vol. XII, (1905), p. 164.

TABLE VIII.

	Percent.	Mol. Prop.
SiO ₂	27.80	464
Al ₂ O ₃	3.76	37
Fe ₂ O ₃	11.81	74
FeO	36.38	507
MnO	1.76	25
MgO	0.38	9
CaO	13.40	239
P ₂ O ₅	0.03	—
Ig. loss	2.24	—
FeS ₂	2.40	—
Total	99.88	

Lievrite, Zomeki Mine, Nagato.

Tremolite.—In the microscopic field of the diopside skarn from the upper part of the Ofuku deposit, there are some needle-like crystals which are clustered in a more or less radial structure. It is distinguished from wollastnite by its weak pleochroism, yellowish to slight emerald green, and its extinction angle is $cZ = 20^\circ$ on 010. This mineral is clearly contact mineral tremolite.

Quartz and calcite.—These two minerals are widely distributed through deposits and in some places are quite abundant. Occasionally they occur in an intimate mixture, forming irregular patches.

The quartz is transparent or semitransparent and always occurs in a massive state and sometimes plays an important rôle as vein stuff. Every kind of silicate mineral which develops in metamorphosed limestone masses, is generally accompanied by this mineral. Under the microscope vein quartz is seen to be formed in the fine granular aggregation, and sometimes it shows a symmetrical band with an irregular mosaic of parallel prisms of quartz crystals arranged normally along both walls. As these comb quartz zones have no intervals between them and their crystals all show micro-structures, it is clear that these crystals are associated with a deeper seated vein which was formed at high temperature and pressure. (Pl. XVII, Fig. 4.) Sometimes quartz occurs in aggregate form in the druse, showing usually large crystals in a terminated form, the largest one being 3 cm. long. This aggregation usually superposes on the skarn

and other minerals, indicating that it was the last mineral to be formed. As is already mentioned on the relation between vein quartz and aplitic rock, in all cases, the quartz is the infiltrated residuary silica in the mineralizing solution which must have been introduced from the consolidating dioritic magma.

Calcite is of the most abundant and wide spread occurrence through the deposits, composing the pure white marble in which the ore and skarn minerals are formed. Most of the mineral may be the recrystallized product *in situ* of the residual calcium carbonate on account of the heated steam expelled from the consolidating magma at the beginning of the contact metamorphism; the hydrothermal solution has carried away a large quantity of calcium from the limestone.

The saccharoidal calcite is replaced by many silicate minerals as well as the ore minerals, filling up on the other hand the interspaces and fissures of these minerals, and occasionally the minute veinlets of calcite mingled with more or less quartz, penetrating all the skarns and ore minerals.

It follows from these facts that the crystallization of the calcite and quartz began a little before the stage of wollastonite and the other minerals and continued to the latest stage of the deposition. It seems especially that the range of the crystallization of the calcite is longer than that of the quartz.

As cited above, the range of the crystallization of these mineral is very long, but it is clear that a large amount of them had crystallized out in the last stage of the formation of the ore deposits.

Primary ore minerals

Chalcopyrite.—This mineral is the principal source of copper in the Ofuku mine. It is uniformly distributed in the lower part of the metamorphic zone, and occurs with quartz gangue commonly accompanied by pyrite, pyrrhotite and magnetite, showing vein forms of various widths.

It is remarkable that the chalcopyrite found in the mine is more or less magnetic due to the intimate intergrowth of pyrrhotite. Under examination by means of the reflecting microscope, the latter fills up the cracks of the former in the fine dendritic or veinlet form (Pl. XVII, Fig. 4). The same fact has been cited by T. Kato on the chalcopyrite found in Hananoyama.⁽¹⁾

(1) T. KATO: loc. cit. p. 30.

On the oxidized zone, the original chalcopyrite has been altered into the various carbonates and oxides of copper, and sometimes into secondary sulphides such as bornite and chalcocite. The veins and veinlets of the chalcopyrite penetrated the main skarn mass and metamorphosed limestone (Fig. 4).

The crystallization of the chalcopyrite took place largely subsequent to the deposition of the main skarn and partly continued to the latest stage of all other ore minerals. But it is partly penetrated by minute veinlets of calcite and quartz in such way as to show that the former is of earlier origin than these two minerals.

Pyrite.—It is present throughout the region in moderate amounts accompanying chalcopyrite. Usually it does not show a definite crystal form, but sometimes many small cubic crystals are scattered in the skarn mass and metamorphic rock.

Under the reflecting microscope, it shows the replacements of chalcocite and limonite without intermediate minerals, and in some parts corroded fragments of pyrite are left in these secondary minerals. The crystallization of the mineral began in the middle stage of the main skarn. Of the metallic ores it was one of the earliest to crystallize.

Pyrrhotite.—This mineral is always associated with the chalcopyrite but is much less abundant. In general it occurs in a massive form and does not show any crystal form. It has been already stated that pyrrhotite gives a magnetic character to the chalcopyrite on account of the intergrowth into the latter.

The greater part of the crystallization of this mineral took place earlier than that of all other ore minerals, but occasionally veinlets of it cut through the other ores showing evidently that the crystallization continued to the latter stage of the mineralization of the sulphide minerals in the mine.

Arsenopyrite.—It occurs in massive or well defined crystal form in skarn masses accompanying other sulphide minerals. The crystal ranges in length from three millimeters to half a centimeter showing the combination of striated brackly dome and a short unit prism.

The arsenopyrite crystallized out at nearly the same stage as the pyrrhotite and a little earlier than some parts of the chalcopyrite and pyrite. This is known because the arsenopyrite is found sometimes covered with one or the other of the latter two minerals.

Galena and Sphalerite.—These two minerals occur chiefly associated with chalcopyrite and pyrite from the lower part of the ore

bodies, especially from the Shinsei adit. They have been found in only small quantities and are of little importance commercially. These small quantities of both sulphide ores are due to the fact that the actual concentrations of lead and zinc in the hydrothermal solution in the district must have been less than those of copper and iron.

These two minerals can be observed generally in the vein quartz showing small crystal form with typical cubical cleavage, but sometimes they may be replaced by other secondary minerals. These minerals react with copper sulphate yielding chalcocite or covellite.

The stage of mineralization of the galena and sphalerite in the mine seems later than that of all the above mentioned sulphide ores.

Molybdenite.—The sulphide of molybdenum occurs as a primary mineral forming small tabular flakes with no economical value. It fills up the minute cracks in the sulphide minerals except galena and sphalerite indicating that it was rather a late deposition. (Pl. XVIII, Fig. 2).

The molybdenite did not actually mineralize within a high temperature, and it is believed that in deposits formed under condition of less intense temperature and pressure, it crystallizes out as minute scales.

Magnetite.—The magnetite is of widespread occurrence in the deposits especially near the outcrops. It is generally rare in quantity and never forms large massive bodies in the Ofuku deposit. This mineral occurs in small irregular aggregations always imbedded in the skarn masses.

It seems that the crystallization is continued from the stage of main skarn to the earlier mineralization of the sulphides.

Scheelite.—It is noticeable that this mineral is found only in the weathering zone⁽¹⁾ in the mine mingled with the oxide ore and quartz. As the depth increases, it seems to grow less and less and finally disappears altogether. The size of the crystal varies in diameter from microscopic to a few centimeters, but generally it is impossible to determine the fine crystal face owing to the decomposition which took place with comparative rapidity along its outer surface, cleavage and cracks extending inward. (Pl. XIX, Fig. 1).

(1) This may be due to the fact that the metamorphosing solutions ascended to the high level when they were at a high temperature.

The pure scheelite crystal passes from milky white to yellowish white in colour showing brilliant cleavage. High specific gravity is also characteristic of the mineral. It is nearly opaque and even in a thin section it is generally too cloudy to determine the optical characters. (Pl. XVIII, Fig. 2). The origin of the scheelite may be due to the reaction between tungsten carried by the mineralizing solution and calcium derived from the limestone.

In general this mineral crystallized out in the little earlier stage than the other ore minerals. For a long time it has been believed that it may be deposited from gas, but J. M. Cambell⁽¹⁾ has emphasized the fact that tungsten is deposited from liquid and not from gas.

Secondary Minerals in Oxidized Zone

Limonite.—The word limonite stands generally for hydrous ferric oxide of yellowish brown colour. It is ordinarily an alteration product which is usually derived from the oxidation of pyrite, pyrrhotite, chalcopyrite and sometimes from the slow decomposition of iron bearing silicate minerals by dilute sulphuric acid.

It occurs, throughout the region especially in the upper part of the deposits, forming a compact earthy mass or stalactite in cavities causing a yellowish or brownish staining of the outcrops. Heavy limonite gossan occurs in the Taishô adit.

Under the microscope, limonite appears as an amorphous film filling up of the interspaces and cracks of the other minerals, but occasionally it shows indistinct aggregate polarization colours due to the aggregation of microscopic grains. It may be cryptocrystalline limonite which was formerly called stilpnosiderite.

As limonite mass contains a large amount of copper, it was worked as one of the important ore. The mass may probably be accompanied by fine secondary copper ores, such as malachite, azurite or chrysocolla and often by siliceous substances.

(1) The following remarks are quoted from Campbell's article: We know that silico-tungstic acid and its alkaline salt are soluble in water and stable even above 350°C. Surely it is more credible that these exist in nature than tin fluoride and hydrofluoric acid. As the evidence is strongly in favor of tungstates having been deposited from liquid and not gas, we assume as a working hypothesis that they along with tin and other associated minerals existed in magma and were transported thence to veins in silico-aqueous solution. (Tungsten Deposits of Burma and their Origin. Econ. Geol. Vol. XV, (1920), p. 529).

The compact mass with brownish colour is locally named "Robaku" or "Waxy ore" and the black coloured variety, "Urushi-ko" or "Lacquer-like ore." The chemical composition⁽¹⁾ of the latter is given in Table IX.

TABLE IX.

	Percent.	Mol. Prop.
SiO ₂	2.99	50
Al ₂ O ₃	4.83	47
Fe ₂ O ₃	74.76	468
FeO	2.28	32
MgO	0.14	4
CaO	2.29	41
Na ₂ O	0.87	14
K ₂ O	0.72	8
P ₂ O ₅	0.34	2
H ₂ O	1.78	99
CuO	9.03	112
Total	100.03	

"Urushi-ko" or "Lacquer-like" ore from the Ofuku mine.

Cuprite.—This copper oxide occurs in the fully oxidized zone closely associated with various other minerals such as malachite, chrysocolla, azurite and native copper. The specimens from the Chugirikô adits show the concentric feature of variations which are the results of a process of the typical oxidized zone. The order of the arrangement of the minerals leading outwardly from the center is cuprite, brown chrysocolla, green chrysocolla and malachite. (Pl. XX, Fig. 3).

The general specimen is massive, and is a beautiful brilliant reddish violet, but *chalcotrichite*, a variety, occurs in the small cavities forming the sparking ruby red aggregates of delicate capillary prismatic crystals.

The cuprite in the deposit seems to have been derived from the oxidation of chalcocite. The cuprite, again oxidized, is converted into native copper.

(1) T. OGURA: The Ore Deposits in the Environs of the Ofuku Mine. Imp. Geol. Surv. Japan, Report No. 82, (1922), p. 34.

Malachite and Azurite.—These minerals may have resulted from the reaction of cupric sulphate in the meteoric water with calcium carbonate which is derived from the country limestone.

In the change from chalcopyrite to malachite and azurite there is a distinct enrichment in the copper. As mentioned above, in many cases these carbonates are associated with copper oxide, such as cuprite. The malachite is found abundantly as a replacement of copper sulphide or as a cavity filler in open spaces showing a radial and concentric structure. (Pl. XX, Fig. 3).

Chrysocolla.—This is an important ore which contains a high grade of copper. Sometimes it occurs as a massive form, about 1 m. long, 0.2 m. wide and 0.4 m. in thickness. The compact part is generally green or emerald green and often shows a brownish or yellowish claylike appearance. The general colouration of the hydrous silicate of copper is the effect produced by thin films of mineral along the cracks and fissures. (Pl. XX, Fig. 3).

Under the microscope, it is almost isotropic, but occasionally shows very feeble double refractions forming a radial arrangement of fine fibrous crystals much like those of chalcedony. The genesis of the mineral in the deposits is due to the alteration of chalcopyrite and cuprite.

Chalcanthite.—This greenish hydrous sulphate of copper is a common mineral developed on the exposed wall surfaces in the deposits. It is probably the residual sulphate of copper converted into malachite, azurite or chrysocolla. It may be rather better to call it copper vitriol. It is clear that the copper sulphate is precipitated in openings or cavities, after a partial evaporation of the water which carries the mineral in solution. Therefore it occurs generally on lower levels, especially in the Shinseikō adit where sometimes small stalactites and stalacmites of the mineral grow in the cavities.

Smithsonite.—This is an uncommon mineral in the mine, occurring as drusy growths associated with malachite and azurite. It reaches half a centimeter or more in thickness showing a fine botryoidal form varying from white to green⁽¹⁾ in colour.

When the zinc sulphate solutions migrate down into the adjacent limestone, they precipitate as smithsonite. There is a slight impoverishment in zinc. The reaction between smithsonite and cupric

(1) It is stated that the greenish colour of smithsonite is due to the adsorption of copper carbonate. (G. D. HUBBARD: Colloids in Geologic Problems. Am. J. Sci. (5) Vol. IV, (1922), p. 105).

sulphate is similar to that given by W. Lindgren⁽¹⁾ for calcium carbonate.

Some specimens of the smithsonite film show a fine lamellae structure. On similar specimens of the mineral in a certain mine, C. G. Laughlin⁽²⁾ described this structure as resulting from a considerable shrinkage in volume caused by replacement.

Covellite and Bornite.—These secondary minerals are rather abundant in the mine. The former is indigo blue in colour and occurs as the result of a replacement of pyrite, chalcopyrite and as the first product of the oxidation of chalcocite after intimate association with malacite and limonite. The latter seems to be the altered product of chalcopyrite and replacement starts generally along the cracks and fissures, especially along the contact part of chalcopyrite and quartz,

Under the reflected microscope, bornite can be recognized as reddish purple spots on the surface or along the fissures of the polished section of chalcopyrite. The bornite is usually confined in the lower part of the zone of enrichment in the deposits as has been suggested by L. C. Graton and J. Murdock.⁽³⁾

Chalcocite.—This cuprous sulphide occurs as one of the secondary products resulting from the replacement of the sulphides of other metals, in massive form or as a surface coat of these minerals.

It has a muddy grayish appearance with compact texture and is always associated with bornite. Examination under a microscope with reflected rays tends to give the impression that all of the chalcocite deposits are secondary minerals which are chiefly formed by the oxidation of chalcopyrite. Occasionally it is derived from bornite, pyrite, zincblende and galena. A thin film of chalcocite is often converted into covellite.

Native Silver and Native Copper.—These minerals are of somewhat rarer occurrence and are common secondary minerals in the deposit. The former appears as small flakes with calcite patches in the specimens collected at the middle and lower levels in the deposits. Though no silver sulphide can be observed at present in the deposits, the genesis of the native silver may be due to the reaction⁽⁴⁾ between

(1) W. LINDGREN: Mineral Deposits. (1913), p. 79.

(2) U. S. G. S. Bull. 690 A (1917) p. 3.

(3) L. C. GRATON and J. MURDOCK: The Sulphide Ores of Copper. Some Results of Microscopic Study. A. I. M. E. Trans. Vol. 45, 1913 p. 30.

(4) This reaction has been proved by the experiments of G. BISCHOF, A. LIVERSIDGE, F. A. MOESTA and others. See, J. H. L. VOGT: Ueber die Bildung des gediegenen Silbers, besonders des Kongsberger Silbers, durch Sekundär processse aus Silberglanz und anderen Silberzen usw. T. KATO, Ore Deposits in the Environs of Hanano-Yama. loc. cit.

heated steam and minute quantities of silver sulphide or argentiferous chalcopyrite or zincblende.

The native copper occurs in dendritic shape and thin flakes at the upper levels of the mine. It is usually found with cuprite and chalcocite, showing the secondary products of copper sulphides and cuprite.

Kaolinite.—At the upper-most horizon of the deposits, small quantities of a yellow stained earthy substance can be observed. It is always associated with skarn minerals and oxidized ore in the metamorphosed limestone.

Under the microscope, it is composed of fine scaly aggregates mingled with a small quantity of minute wollastonite crystals. It is light yellow in colour showing slight pleochroism and strong double refraction. This mineral may be *nontronite*, a sort of kaolin.⁽¹⁾

The genesis of nontronite has been discussed by many authors such as E. Weinschenk,⁽²⁾ A. Bergeat,⁽³⁾ T. Kato,⁽⁴⁾ D. Seridentschenko,⁽⁵⁾ etc. On the occurrence of the mineral at the Kitabira deposits, Nagato, T. Kato gives the following descriptions which may be quoted here for reference. "Nontronite is believed to be formed, not only by pneumatolytic and hydrothermal actions on rock forming silicates, but also by the action of acidic descending waters containing FeSO_4 on silicates such as wollastonite, hornblende and others. The case now under consideration may be interpreted by the fact that the hendenbergite was decomposed by meteoric waters dissolving much sulphuric acid, various kinds of sulphates and other compounds, resulting in the formation of limonitic masses and a small amount of nontronite as separate masses."

The writer believes that in the Ofuku deposit the nontronite may have been formed by the action of a solution of iron sulphate on the decomposed product of wollastonite.

(1) E. Weinschenk regarded nontronite as analogous to kaolin, but lately W. Noll stated that very few analyses agree with kaolin and also that dehydration curves and X-ray powder photographs show no relation to kaolin. (E. Weinschenk: Zur Kenntniss der Graphitlagerstätten. Abh. d. kgl. bayer. Akad. d. Wiss. (II kl.), XIX, Bd. II Abth (1898), p. 563. and W. NOLL: Zur Kenntniss des Nontronits. Chemie der Erde, Bd. V. (1930) P. 373).

(2) E. WEINSCHENK: Ibid.

(3) A. BERGEAT: Nontronit, gebildet durch die Einwirkung von Eisensulfatlösung auf Wollastonit. Centralbl. f. Min. u. s. w. (1909), pp. 161-168; Nontronit von Gellivara (Lappland). Centralbl. f. Min. u. s. w. (1914), pp. 105-108.

(4) T. KATO: Ore deposits in the Environs of Hananoyama. loc. cit. p. 79.

(5) D. SERDINTSCHENKO: Ueber die Nontronite aus zwei südrussischen Graphitlagerstätten. Centralblatt Min., Abt. A. (1929), p. 47.

Secondary Tungsten Mineral.—Some crystals of scheelite at the upper horizon of the deposits assume a greenish yellow colour and formerly were called by the name of *cuproscheelite*. But in a thin section the changes are seen to have taken place only along the margin of the cleavages and cracks of the crystals and it is clear that the so-called cuproscheelite is a mixture of cuprotungstate and scheelite as has been suggested by F. L. Hess.⁽¹⁾ In this mine such samples are called “Kusairo-jyuseki” or “Grass coloured scheelite” by the miners.

In general scheelite dissolves rather readily and forms soluble salts or colloidal compounds. R. W. Gannett⁽²⁾ has described many experiments relating to the effect of various solutions, resembling ground water, on the tungsten minerals. His experiments show that carbonate solutions do not attack tungsten minerals, but sulphuric acid⁽³⁾ on the scheelite will dissolve some tungsten, and leave substances such as tungstic acid. This would indicate that sulphuric acid solutions acting on a tungsten deposit would remove some tungsten and decompose some into tungstite. The green yellowish colour of the secondary tungsten minerals is due to the cupric salts which are present in ground waters, that is, if any tungsten did dissolve, it would probably precipitate to form a hydrous cupric tungstate.

Genesis of the Ore Deposits

The metalliferous deposits of the Ofuku mine are all of epigenetic origin and are believed to be closely connected with the intrusion of the diorite mass, though there can not be observed true contact faces between igneous rocks and ore masses in the mine. In other words, the source of the diorite magma and of the mineralizing solutions which deposited the silicate minerals and metallic ores may be regarded as the same. When the super-heated metamorphosing solutions issued from the crystallizing dioritic magma and ascended upward, they were capable of producing recrystallization and rearrangement the Palaeozoic sedimentaries, especially limestone and limy rocks which they traversed, dissolving others and precipitating many silicate minerals and metallic ores.

(1) F. L. HESS: Tungsten Minerals and Deposits, U. S. G. S. Bull. 652, (1917), p. 32.

(2) R. W. GANNETT: Experiments Relating to the Enrichment of Tungsten Ores. Econ. Geol. Vol. XIV. (1919), p. 68.

(3) Sulphuric acid will be derived from the sulphides usually present in ore deposits. (W. H. EMMONS: The Enrichment of Ore Deposits. U. S. G. S. Bull. 625, (1917), p. 83).

Judging from their forms the deposition of these minerals may be said to have served as channels for the escape of portions of the magmatic emanation from deeper position, along the lenticular limestone resulting in some metamorphic action upon the neighbouring rocks.

The relations of the geology and ore deposits of the Ofuku mine and its environs may be imagined as shown in the following diagrammatic sketch. (Fig. 6).

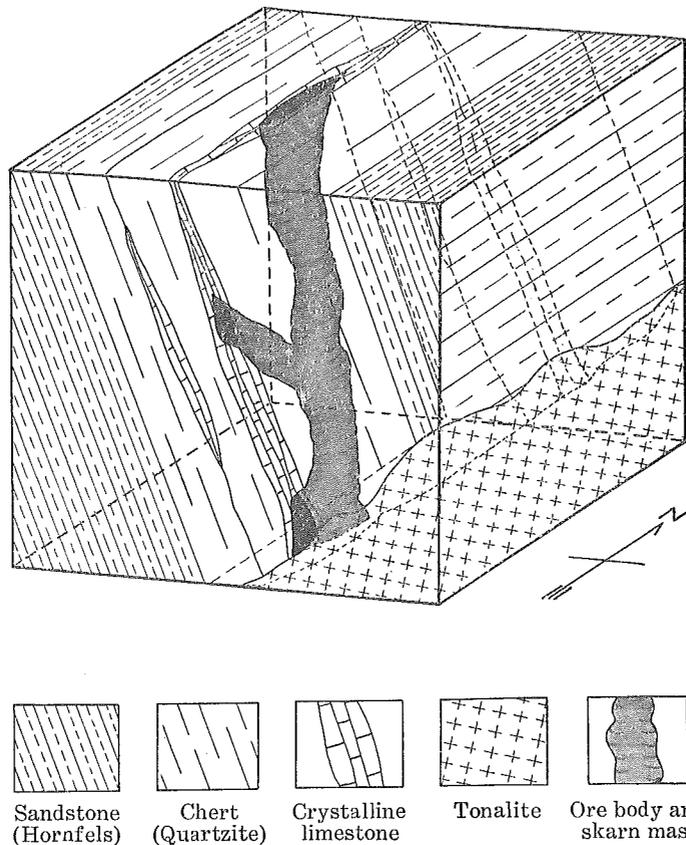


Fig. 6. Stereogram illustrating location of ore body and skarn mass along the lenticular limestone at the Ofuku mine.

It is believed that the hydrothermal solutions were composed of a large percentage of water containing various materials and volatile matters held in solutions. Many silicate minerals and metallic ores

were precipitated from the aqueous solutions under favorable conditions when the solutions rose up to the zone of less pressure and colder rock formations.

The water in the solutions may have resulted from the heating of surface water or from the solidifying magma⁽¹⁾, perhaps it may have been furnished from both of these sources. It is impossible to determine the accurate chemical characters of the metamorphosing solutions which composed the Ofuku deposits, but it may be approximately inferred by a consideration of the substances deposited from them. Though it was continually changing in character, at the beginning of the mineralization they were saturated chiefly with silica, alumina, iron, copper, sulphur including small amounts of lead, zinc, silver, gold and some other elements.

Such elements as fluorine, bismuth, boron were almost altogether absent in the solution. This seems to be tenable from the fact that fluorite, bismuth or topaz and tourmaline which are commonly regarded as characteristic of typical pneumatolytic deposits have not been discovered.

By observing the occurrence of the contact metamorphosed minerals and metallic ores, a person can roughly determined the succession of the stages of mineralization in the deposits, indicating the chemical change of the hydrothermal solution on account of the differences in the physical conditions during the period of deposition. It is very difficult to find a definite solution for the problem of temperature at the time when the various minerals crystallized out from the hydrothermal solution, for the temperature of reaction varies in proportion to the degree of pressure and the physico-chemical relation in these solutions is very complicated. But fortunately some probable temperature limits of the crystallization of minerals have been roughly determined by the physico-chemical experiments of many scientists.

According to their experiments on the variable minerals formed in the contact zone, it has been made clear that the general silicate rocks may consolidate at a temperature of 500°C. to 1100°C. that is

(1) It is generally believed that water exists in magma as a liquid above its critical temperature in combination as hydroxyl with silica. A. Harker states that on this supposition the magma, as it cools, will separate progressively into two partial magmas, one containing most of the silicate and other minerals and the other with a preponderance of water and other volatile substances. The latter, which we may call the aqueous solution will collect especially in marginal parts of an intrusive body where the cooling and consequence separation begin. He calls this solution "the residual or mother liquor" at the end of the process of crystallization. (See Natural History of Igneous Rocks. 1909).

the heated aqueous solution probably exceeded the critical temperature of water.⁽¹⁾

Judging from these facts, there can be no doubt that the solutions which formed the deposits in the district under discussion, must have been at certainly higher temperature and at an earlier stage of contact metamorphism, the mineralization of some minerals is due to the pneumatohydrothermal metasomatism which process is considered to take place just after or during the consolidation of igneous magma.

It is noticeable that the boundaries between the saccharoidal limestone and the mass, or vein of skarn minerals, are in general, very sharply defined. This fact leads to the suggestion that the development of the silicate minerals which were originated from the hydrothermal solutions, might have taken place after the great deformation of the original country rocks on account of the igneous intrusion, indicating some recess between these two stages of metamorphism⁽²⁾.

The problem whether the volume has increased or decreased as a result of metamorphism, has been a subject of inquiry by many scientists⁽³⁾.

(1) It is indicated by the experiments of many scientists that above 1190°C. wollastonite is unstable. The wollastonite appears to have been formed at on of the early stages of mineralization in the contact zone. See E. T. ALLEN, W. R. WRIGHT & F. E. WRIGHT: On Wollastonite and Pseudowollastonite. *Am. Jour. Sci.* (4) Vol. 21, (1906), p. 89. A. L. DAY and E. S. SHEPHERD: The Lime-Silica Series of Minerals. *Am. Jour. Sci.* (4) Vol. 22, (1906), p. 290. G. A. RANKIN & F. E. WRIGHT: The Ternary system Ca-Al₂O₃-SiO₂. *Am. Jour. Sci.* (4) Vol. 39, (1915), p. 1. V. M. GOLDSCHMIDT: Die Gesetze der Gesteinsmetamorphose. *Vidensk. Skr., Mat.-natur. Klasse*, No. 22 (1912).

Experiments made with garnet by Dr. MERWIN at the Geophysical Laboratory of the Carnegie Institute of Washington show that it loses its birefringence after it has been heated for a few hours at about 800°C., and does not regain it after several hours heating at 600°C. This fact indicates that most of the metamorphism takes place at temperatures lower than 800°C. For the garnet which is a variety having distinct double refraction, formed probably almost contemporaneously with the wollastonite. See C. W. WRIGHT: *Geology and Ore Deposits of Copper Mountain and Alaska*. U. S. G. S. Prof. Paper 87 (1915) p. 108.

W. Lindgren & Whitehead attempted to determine the temperature by the solubility curve of sodium chloride, which salt is present in sharp cubes in fluid inclusions in quartz in a contact metamorphic deposit at Zimapan, Mexico. They concluded that the temperature of formation was about 400° to 500°C. (*Econ. Geol.* Vol. 9 (1914), pp. 435-462). See also, W. LINDGREN: The Relation of Ore Deposition to Physical Conditions. *Econ. Geol.* Vol. II (1907) pp. 105-127.

(2) It seems that the fact can be commonly observed in a general metamorphic ore deposit, for some examples have been described by other authors. See J. B. UMPLEBY: The Genesis of the Mackay Copper Deposits, Idaho. *Econ. Geol.* Vol. IX, (1914) and Prof. Paper 97, U. S. Geol. Survey, (1917). M. WATANABÉ: Geological Structure of the Ore Deposits of the Yakuki and the Ono Mine. *Sci. Rep. Tôhoku Imp. Univ.* (Third Series) Vol. I (1922), p. 62.

(3) J. B. UMPLEBY: The Genesis of the Mackay Copper Deposits, Idaho. *Econ. Geol.*, Vol. IX (1914), p. 344. W. L. UGLOW: Review of the Existing Hypotheses on the Origin of the Secondary Silicate Zones at Contact of Intrusives with Limestone. *Econ. Geol.* Vol. VIII, (1913), pp. 19-50 and W. Lindgren: *Mineral Deposits*, (1919), p. 720.

It has already been mentioned that the contact metamorphosed phases show the addition of large amounts of silica, alumina, ferrous oxide and other metallic elements and the removal of vast amounts of carbon dioxide and water. Though there has been such a great chemical change in the rock mass by intense metamorphism, it is generally believed that during the metamorphism the volume change of the rock mass has been slight and for the present consideration the volume will be constant⁽¹⁾.

The creation of many skarn minerals found in the deposits is due to the metasomatic process between limestone and highly heated metamorphosing solutions which were originated from the consolidating magma.

As is shown in Table I, the unaltered limestone found in the district is nearly pure calcium carbonate, with low content of iron, magnesia, silica and other impurities. This indicates that a vast amount of foreign materials in the skarn minerals have been introduced from an outside source, that is, they were contained originally in the hydrothermal solutions, though the calcium in these minerals is believed to have been derived by the solutions from the limestone through which they passed. In other words, these skarn minerals are replacement products of the limestone on account of the important addition of silica, iron and other elements in the solution⁽²⁾.

(1) B. S. BUTLER: Relations of Ore Deposits to Different Types of Intrusive Bodies in Utah. *Econ. Geol.* (1915) and the Ore Deposits of Utah. U. S. G. S. Prof. paper, 111, (1920). Butler has explained the relation to addition and removals of constituents showing the supposition of essential constancy in volume by the diagrammatic text figure.

(2) The formation of skarn minerals has been a remarkable subject for discussion from an early date. It was discussed especially about eighteen years ago by many geologists. Some one maintained that the origin of skarn minerals formed by limestone contacts is due to the recrystallization of the original rock without any addition or loss of material except water and carbonic acid. It seems however, that many geologists agree to the conclusion that the creation of skarn-forming minerals is generally due to a process of metasomatism by emanations or highly heated metamorphosing solutions expelled from the consolidating magma. See W. L. UGLOW: Review of the Existing Hypotheses on the Origin of the Secondary Silicate Zones at Contact of Intrusives with Limestone. (*Econ. Geol.*, Vol. VIII (1913), pp. 19-50, and 215-234). Secondary Silicate Zones: A Reply to Criticisms by J. F. KEMP & C. A. STEWART. (*Econ. Geol.*, Vol. IX (1914), pp. 175-183). D. H. HIGGINS: Secondary Silicate Zones (Discussion). (*Econ. Geol.* Vol. IX (1914), pp. 73-77.) C. A. STEWART: The Origin of Secondary Silicate Zones. (*Econ. Geol.*, Vol. IX (1914), pp. 278-281). J. F. KEMP: Garnet Zone. (*Min. & Sci. Press.*, Vol. 92 (1906), pp. 220-221). Secondary Silicate Zones (Discussion). (*Econ. Geol.* Vol. IX (1914), p. 282). W. LINDGREN: The Origin of the Garnet Zones and Associated Ore Deposits. (*Econ. Geol.*, Vol. IX (1914), p. 283-292, and *A. I. M. E. Trans.* 48 (1918), pp. 201-208). C. K. LEITH: Recrystallization of Limestone at Igneous Contact. (*Econ. Geol.*, Vol. IX (1914), pp. 292-299 and *A. I. M. E. Trans.* 48 (1915), pp. 209-215).

For a short these metallic minerals were carried by the same medium and each ore deposited when the temperature was suitable for its deposition.

The above facts lead to the conclusion that the metallic minerals have generally been formed later than as well as contemporaneously with the silicate minerals⁽¹⁾. These conclusions agree in general with those arrived at by others in the study of similar deposits in fact.

Considering the occurrence, both calcite and quartz seem to have mineralized during a very long period compared with other minerals.

(B) The Sanjô Deposits

General Feature—The Sanjô deposits⁽²⁾ are found about two kilometers north of the forementioned Ofuku deposits and their positions are on a much higher level than those of the latter. The general appearance of the geology of the vicinity of the deposits is almost similar to that of Ofuku.

The sedimentaries in the vicinity generally strike N. 20° E. dipping toward the east side at an angle of 60–70°. The surface contact of the tonalite mass and chert is about 500 meters west of the deposits, but it is characterized by a narrow porphyrite dike penetrating the deposit in the direction N. 45° W. The details of the petrographical and chemical characters of this dike have already been mentioned. (p. 85). The natures of the sedimentaries, chert, sandstone, and lenticular limestone, are mega- and microscopically entirely similar to those in the Ofuku mine.

(1) On the paragenesis of many minerals in the Ofuku mine, T. KATO had already concluded that the metamorphosing solutions which were in the first stage of metamorphism very siliceous (rich in silica and absorbed lime), changed in the second stage (stage of garnetization) to rather basic ones, rich in iron and silica with lime and little of alumina) and charged with more or less sulphide ores, and finally, in the last stage, the nature of the solutions became exceedingly basic, very rich in sulphide of copper and iron (chalcopyrite) with only subordinate amounts of silica and others. (T. KATO: Ofuku Mine. loc. cit. p. 29).

(2) 長門國美禰郡於福村山上鑛山. This mine was formerly called Ofuku mine and has been studied by the following authors: N. FUKUCHI: Mineral Paragenesis in the Contact Metamorphic Ore Deposits, found in Japan. Beiträge zur Mineralogie von Japan, herausgeg. von T. WADA, Nr. 3, (1907), pp. 88–89. T. OGURA: On the Mines in the Environs of Ofuku (In Japanese), Rep. Imp. Geol. Surv. Japan. 82, (1921), pp. 36–42. J. T. CHANG: The Geology and Ore Deposits of the Ofuku District, Prov. Nagato, Ms. (1922).

The greater part of the two parallel lenticular⁽¹⁾ limestones interstratified in chert, are generally developed underground, and only a small part of them can be observed on the surface in the vicinity of the mine.

Ore Deposits—As shown in the text figure, in the Sanjô mine, two parallel ore and skarn masses develop along the lenticular limestones. The one is situated along the eastern side of the western lens and the other mass is found along the western wall of the eastern lens. The upper part of the western mass, with an area of 4000 sq. meters, which has been dug out as an open air cutting on the surface, is elliptical in shape and extends in a north-south direction.

The ore deposits developed along the western lenticular limestone are cut at two levels, the Ichigô adit and Chûgiri adit. The former is on a level with the open cutting. The latter is 30 m. below the Ichigô adit and was cut along the porphyrite dike in a northeast direction.

The metallic ores and gangue minerals from the open air cutting are as follows; chalcocite, azurite, cuprite, chalcopyrite, scheelite, wollastonite, garnet, diopside mingled with small quantities of calcite, quartz and others.

The two parallel beds of garnet skarn crop out on the surface owing to their resistance to erosion. The garnet crystal shows a fine reddish brown colour and is a rhombic dodecahedron, ranging generally from half a centimeter to four centimeters in diameter. It belongs to the iron garnet, andradite.

It is noticeable that the garnet skarn contains a moderate quantity of scheelite crystals in every case. The scheelite is yellowish milky white in colour and some crystals reach seven centimeters in diameter, but those with a diameter less than one centimeter, are of very common occurrence⁽²⁾. In many cases, it shows fine crystal faces, and predominant development of domes can be easily observed.

The secondary tungsten mineral is also accompanied by scheelite with the same occurrence at the Ofuku deposits. (See p. 114).

The production of scheelite from the mine in three years, from 1917 to 1919 was about 47,040 pounds.

(1) It is difficult to determine the correlation of these lenticular limestones to those of the Ofuku mine.

(2) According to the chemical analyses at the Imperial Geological Survey of Japan, the scheelite contains 52.36% of tungsten and the secondary tungsten ore contains 53.73% of tungsten and 2.32% of copper. The green yellowish colour of the secondary tungsten mineral is due to cupric salts. (Rep. Imp. Geol. Surv. Japan, No. 82 (1921) p. 41).

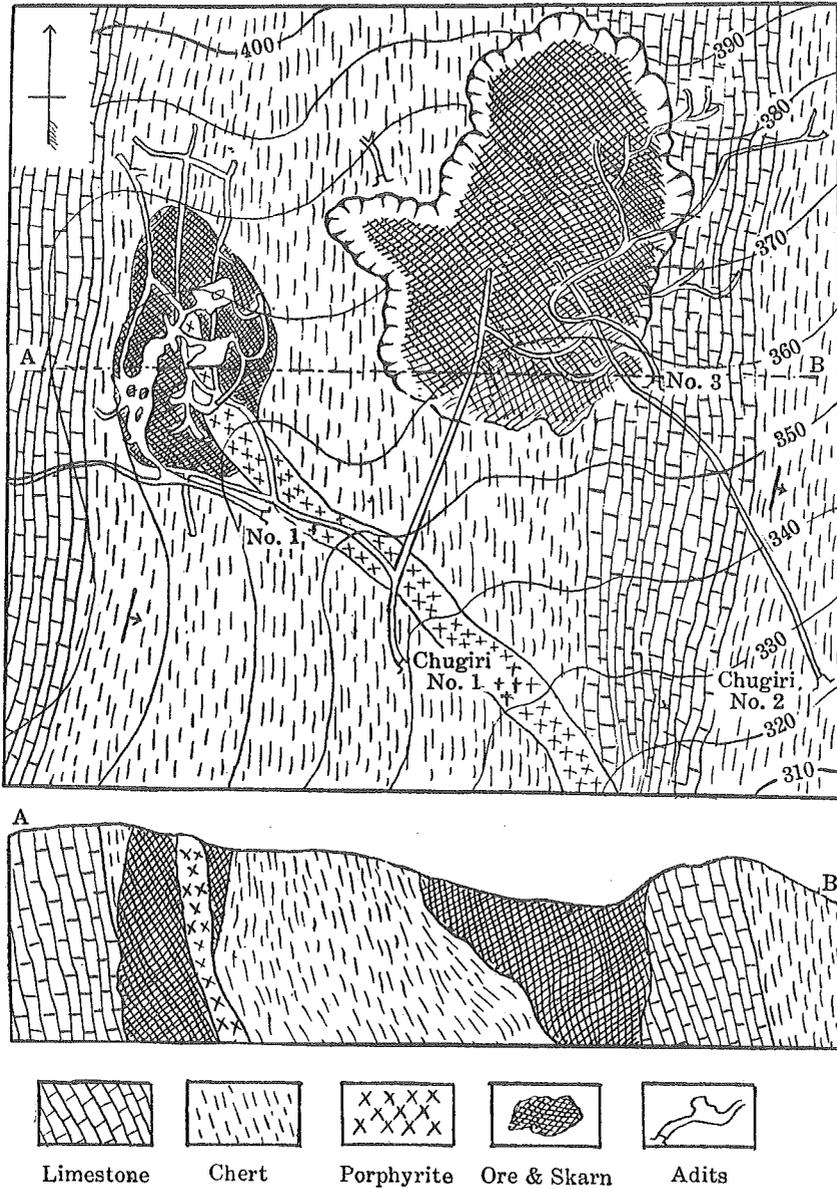


Fig. 7. Geologic sketch map of the Sanjō mine showing under-ground working. Scale 1 : 800.

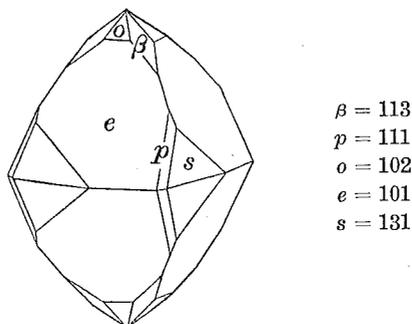


Fig. 8. Crystal of scheelite from the Sanjō mine.⁽¹⁾

In the deposits, wollastonite is an important contact mineral next to garnet. It occurs in the saccharoidal limestone in massive form, and also along the cracks of the chert.

The ore deposits of the Sanjō mine were genetically closely related to the tonalite mass, though there is as yet no evidence of direct connection between them. The porphyrite dike penetrates the sedimentaries and even the ore mass itself, giving a slight impregnation of pyrite to the skarn mass. It indicates that the ore mass had deposited before the penetration of the porphyrite dike.

The ore deposits of the mine are almost similar to those of the Ofuku mine in occurrence and characters. It is clear that these deposits occurred under the same condition and were formed by nearly the same processes.

(C) The Nagawo Deposit

The Nagawo mine⁽²⁾ is located a little northeast of the Sanjō mine, looking down the Furuya⁽³⁾ valley.

The ore deposit occurs in a small lenticular limestone intercalated in chert. No previous study has been made of the deposit except for the work of J. T. Chang⁽⁴⁾ in 1921. Formerly it produced a small amount of copper ore, but now it is of no value from an economical point of view.

The ore mass found in the deposit is composed of chalcopyrite, pyrite, pyrrhotite and the other oxide ores. The gangue minerals associated with the metallic ores are, arranged in order of abundance, as follows: calcite, quartz, wollastonite, garnet, diopside etc. It is

(1) This figure is copied from T. WADA's "Minerals of Japan."

(2) 長門國美禰郡於福村長尾鑛山. (3) 古谷.

(4) J. T. CHANG: loc. cit.

characteristic that there is a moderate quantity of fine crystals of lievrite. In general this mineral is inclosed in the skarn mass of the garnet and diopside, but in other cases it fills up the interspaces of the fissures of the skarn mass and occasionally imbeds a perfect basal section of quartz crystal. (Pl. XVII, Fig. 3). These facts indicate that the crystallization of the mineral began at a slightly earlier stage than the main skarn and stopped after the cessation of deposition of the main skarn. The largest crystal of the mineral attains a diameter of several decimeters in diameter and a length of four or more centimeters.

Wollastonite occurs as a white mass in the saccharoidal limestone, forming an aggregation of fibrous crystal, with radiating structures. Sometimes the wollastonite skarn contains a considerable amount of quartz grains, showing that the mineralizing solutions at early stages were exceedingly siliceous and partly reacted with lime carbonate yielding wollastonite and some residual silica crystallized out as quartz. Diopside skarn is dark green in colour, associating with garnet and calcite crystals.

The Nagawo deposits were formed through a process of metasomatism of hydrothermal solutions on limestone and under exactly the same conditions as those of the Ofuku and Sanjô deposits and therefore, need no further description here.

(D) The Fukurei Deposit

General Features.—The Fukurei⁽¹⁾ mine is situated about one kilometer south-west of the town of Kanayama and on the western flank of the steep slope of the Ofuku plateau.

Geologically the region is composed of thick limestone and shale with strike N. 20° E. and dip 40–60° to east and two parallel porphyrite dikes which penetrate the two sedimentaries.

In the neighbouring part of the dikes the limestone is recrystallized into a granular saccharoidal aggregation of calcite and the shale is changed into black hornfels, both cases being due to the action of the mineralizing solutions. One of these porphyrite

(1) 長門國美禰郡於福村福嶺鑛山。

T. OGURA: The Ore Deposits in the Environs of the Ofuku Mine. (In Japanese) Report Imp. Geol. Surv. Japan, 82 (1921), pp. 42–46.

J. T. CHANG: Geology and Ore Deposits of the Ofuku Mine District, Nagato, (1922), Ms., pp. 85–89.

J. SUZUKI: Contact Metamorphic Ore Deposit of the Fukurei Mine. (In Japanese). Jour. Geol. Soc. Tokyo, Vol. XXXIII (1923), pp. 1–15.

dikes, is about 20 meters in breadth and strikes a little east of north and dips steeply to the west, being approximately parallel in strike to that of the sedimentaries neighbouring the dike. The other small dike, measuring about 4 meters in the widest place is situated 20 meters west and subparallel to the former. The petrographical characters of these dikes, have already been described in detail on page 86. It is clear that the ore deposits are closely related to the dikes which might be derived from the dioritic mass.

Ore Deposit.—The ore deposits in the mine develop chiefly in the limestone, immediately in contact with one of the porphyrite dike, and the development of the ore masses coincides with the strike and dip of the dike. (Fig. 9).

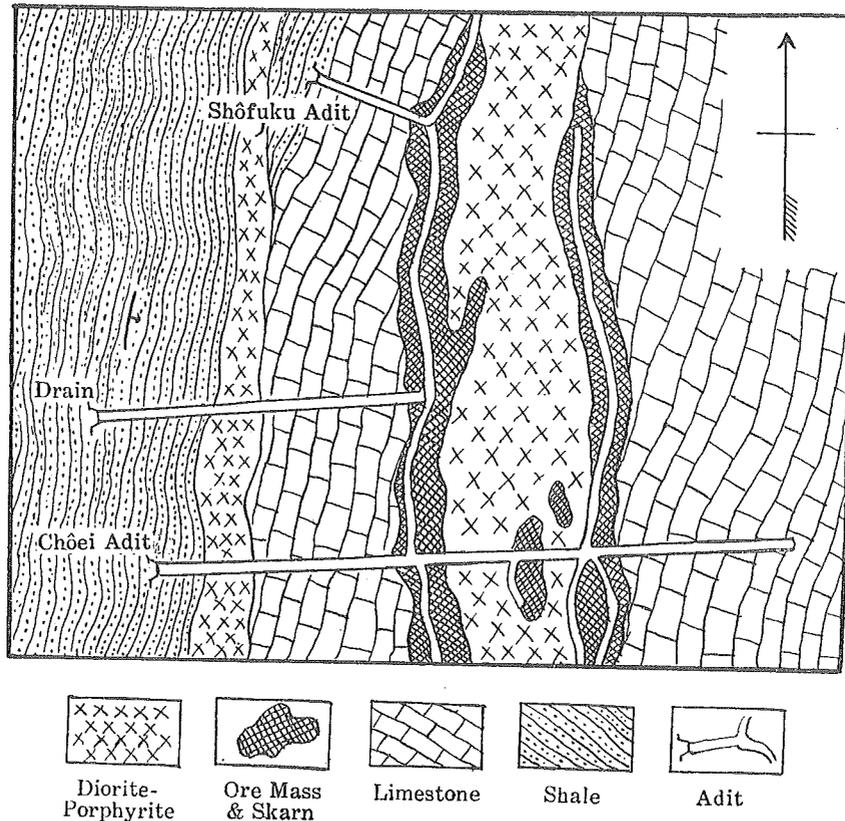


Fig. 9. Under-ground map of the Fukurei mine, showing the geological position and form of the deposits at the level of the Shōfuku and Chōei-adits. Scale 1 : 800.

This mine has two parallel levels which are driven toward the east at a depth of about 30 meters. The ore mass is composed chiefly of iron oxide, magnetite and limonite, and subordinately of sulphides such as chalcopyrite, pyrite and molybdenite, accompanied by many gangue minerals such as garnet, diopside, epidote, calcite and quartz.

The mineral paragenesis of the mine bears some resemblance to that of the Ofuku, Sanjō and Nagawo mines which belong to the first type. But it is remarkable that the deposits are almost entirely lacking in wollastonite, vesuvianite, hedenbergite, lievrite, scheelite and pyrrhotite. The silicate minerals occur chiefly in saccharoidal limestone and some in igneous rocks. In general, the masses of silicate minerals and metallic ores have sharp contacts with the saccharoidal limestone indicating that the formation of these masses must have been later than the recrystallization of the limestone.

When the silicate masses are in contact directly with the porphyrite dikes, they show no sharp line marking the boundaries between the areas of these rocks. But in passing from the skarn mass to the porphyrite dike, there is a decrease in garnet, an increase in diopside, and an appearance of feldspar and titanite as constituents. As already mentioned, the origin of these three minerals, diopside, titanite and some quantities of feldspar, may be due to the assimilation of limestone into the porphyrite magma.

Small masses of metallic ores enclosed in the dikes indicate that when the dikes became effectively solid, fissures in them may have been injected with the still fluid solution. In other words, the deposition of the metallic ore mass took place after the consolidation of the igneous rocks. Owing to the great fluidity, the aqueous solutions may have been injected to a great distance in a vertical direction.

Mineralogical Characters of the Deposits.—Magnetite occurs, for the most part, in fine-grained massive form, and sometimes every grain shows well developed octahedral crystals. The diameter of the crystal ranges from 1 to 3 mm. It is commonly developed in garnetized phases of altered limestone accompanying some other sulphide ores.

Sometimes the magnetite fills up the interspaces of the well-crystallized garnet grains and forms garnet-magnetite-fels which consists chiefly of a granular mixture of these two minerals. But occasionally, minute veinlets of the garnet can be seen cutting the magnetite mass while the calcite partly fills up the interstices and small druses of the magnetite grains. (Pl. XVIII, Fig. 3).

The presence of gangue minerals and some sulphide minerals in the magnetite mass, is the chief factor which tends toward lowering the grade of the iron ore. In general the crystallization of the magnetite began at the same stage of the formation of the main skarn and the cessation was later than all the other sulphides except the chalcopyrite.

Some parts of the magnetite show a reddish colour on account of the presence of limonite which is an alteration product of magnetite and iron pyrite. The latter is disseminated in crystals through the magnetite and gangue minerals and varies in quantity in different parts of the ore beds. Chalcopyrite and molybdenite have been found in the mine, but in comparatively small quantities. The former occurs in massive form mingled with magnetite, and sometimes penetrates the magnetite mass in vein form. The latter sulphide occurs in small flakes filling up the other minerals indicating that the mineralization of the sulphide took place under a condition of less intense temperature.

The gangue minerals in the mine are garnet, epidote, diopside, quartz and calcite. The mode of occurrence of the minerals is generally similar to that in the fore-mentioned mines.

A microscopic study of numerous specimens of the contact rock shows that it is important in altered wall rocks, mostly limestones and in part in altered dike rocks.

Garnet is the predominant silicate mineral in the deposits forming a granular aggregation in the recrystallized calcite mass. In general, the garnet skarn contains many other minerals such as magnetite, calcite and diopside. Every grain shows rhombic dodecahedron crystals of 1 mm. to half a cm. in diameter. It is dark brown or greenish brown in colour, but under the microscope, it is nearly colourless showing optic anomaly. This garnet belongs to the andradite and is the earliest product of mineralization in the deposits.

Diopside occurs also as a compact aggregation forming the diopside-fels. The interspaces of the aggregation are filled up with quartz and calcite. The prismatic crystals show complete cleavage and the extinction angle is $c^{\wedge}Z = 38^{\circ}$ on 010. Judging from its occurrence it seems to have crystallized out during nearly the same stage as the garnet, though the beginning of the crystallization was a little later than that of the garnet.

Sometimes the skarn-forming diopside is in contact with the diopside which crystallized out directly from the porphyrite magma. But under the microscope the former contains small grains of garnet,

while on the other hand, the latter contains minute crystals of apatite and magnetite as inclusions. The same occurrences of diopside in a certain mine in Mexico, has been described by A. Bergeat⁽¹⁾ who has also made a difference between two types of diopside by the kinds of inclusions. Epidote occurs as greenish prismatic crystals though it is very scanty in volume, compared with the garnet and diopside. The stage of crystallization of the mineral is much later than that of those two silicate minerals.

Quartz is generally well crystallized and associated with garnet and diopside skarn, but it is very scanty in quantity.

Calcite occurs in a saccharoidal form, resulting from the recrystallization of the original limestone but sometimes appears filling the interspaces of the other minerals indicating that it was the last mineral to form.

In general it seems that the ranges of crystallization of the calcite and quartz are very long during the mineralization of the deposits. Some parts of the magnetite mass show a reddish colour due to the presence of limonite as an alteration-product.

Genesis of the Fukurei Deposits.—The metallic ores and skarn minerals in the Fukurei deposits, develop commonly along the contact faces of limestone and porphyrite dikes and are quite often inclosed in the igneous mass itself.

These facts indicate that the upward movements of the metamorphic solutions took place after the solidification of the magma, along the fissures in or near the igneous mass.

The formation of the deposits is due to the metasomatic process on limestone by metamorphosing solutions which were originated from the magma.

The ore deposits in the Fukurei mine are mineralogically and genetically almost similar to those of the fore-mentioned mines, Ofuku, Sanjô and Nagao belonging to the first type. The most characteristic differences between the Fukurei deposits and these other mines may be described as follows:—

1) At the mines belonging to the first type, the ore deposits develop generally very far from the point of contact with the igneous bodies which may have carried the metamorphosing solutions, but in the Fukurei mine, the deposits occur at the immediate contacts of the porphyrite dike.

(1) A. BERGEAT: Der Granodiorit von Conception del Oro in Staate Zacatecas (Mexiko) und seine Kontaktbildungen. Neues Jahrbuch, B: B. XXIII (1906), p. 421.

2) The Fukurei deposits are composed of magnetite as the predominant ore mineral though it is scarcely recognized as an ore mass in the first type. It seems that the occurrence of the large amount of the magnetite is closely related to the characters of the solutions and to the condition of the time of the igneous intrusion⁽¹⁾.

3) It is noticeable that the Fukurei deposits are entirely lacking in wollastonite, vesuvianite, hedenbergite, lievrite, scheelite and pyrrhotite notwithstanding that these minerals are commonly recognized in mines of the first type. The small amount of quartz and copper ores is also characteristic in the mine comparing it with the others.

Judging from the above data it seems highly probable that the metamorphosing solutions brought by the porphyrite dike in the mine, were very basic in nature being rich in iron but very scanty in silica and copper due to the process of magmatic differentiation.

As the paragenesis of the contact minerals has shown, the mineralization of the Fukurei deposits began at the epoch corresponding to the beginning of the second stage of the metamorphism in the deposits of the first type. It therefore indicates, that the temperatures at the mineralization of the Fukurei deposits were probably never high enough to allow wollastonite, vesuvianite or other high temperature products to be formed.

(E) The Miné Deposits⁽²⁾

The Miné deposits are situated about 3 km. southward from the town of Kanayama along both sides of the river Asa. The ore deposits appear as tabular masses developing along the contact face of

(1) Concerning the source of the oxides of iron, magnetite and specularite, in a contact deposit W. H. WEED has stated as follows. "In as much as the disassociation of the interstitial water of the sedimentary rocks by the intrusion of highly heated magma would provide a sufficient supply of oxygen, the occurrence of such ores, produce by reaction with the iron compounds present, would be explained while the fact that such deposits are almost entirely confined to the immediate vicinity of the igneous contact can be readily understood." (W. H. WEED: Ore Deposits near Igneous Contacts. A. I. M. E. Trans. Vol. 33 (1911), p. 715 and Emmons and others, Ore Deposits (1913), p. 393.)

At the Ofuku and Sanjō mine, the magma and hydrothermal solutions were so hot that the mineralizing solution ascended to a very high point, but at the Fukurei mine, the minerals were deposited only at the periphery of the intrusive mass indicating that the solutions had consolidated before they reached higher levels. It is clear that the porphyrite magma itself had a lower temperature than the tonalite magma.

(2) 長門國美禰郡於福村嶺鑛山.

the Palaeozoic limestone and sandstone. They are one meter or more in thickness and often show a fine lenticular form, but there are only very small quantities, having no economical value at present.

Near the ore masses limestone was metamorphosed into a saccharoidal variety and the slate altered into dark compact hornfels which contains abundant minute crystals of biotite and garnet.

The ore deposits are composed essentially of pyrrhotite, chalcopyrite, pyrite and magnetite accompanied by a small quantity of skarn-forming minerals such as wollastonite, garnet and diopside.

Though it is impossible to recognize the direct relation to the igneous rocks, the genesis of these deposits is clearly due to the metasomatism on limestone by the hydrothermal solution discharged from the porphyrite dikes or tonalite mass which developed far below the deposits.

(F) The Takara Deposit⁽¹⁾

As already mentioned in the geological descriptions a great fault intersects the Asa river valley.

It is of considerable importance to note that the fault line passing near Irimizu⁽²⁾, is closely related to the ore deposit.

The Takara deposit develops along the brecciated fault line showing an irregular pipe form. The brecciated zone along the fault has produced conditions favorable to form a channel of escape for the mineralizing solutions which charged from the cooling tonalite mass indicating that the deposition of metallic ores took place after the tectonic movement in the district.

In general the brecciated fragments are angular in form, one cm. to several cm. in diameter but occasionally some of them have been corroded by the hot solution so that they have the appearance of a boulder conglomerate. In several instances the solution replaced the outer part of these fragments and deposited the metallic minerals as ring ore, and sometimes large blocks of limestone breccia were entirely replaced by the ore (Pl. XIX, Fig. 3). Metasomatism was carried on most extensively in limestone, for the degree of the replacement is closely related to the characters of the material of the brecciated fragments.

The essential components of the products of igneous metamorphism in the deposit, are pyrrhotite and chalcopyrite associated with a small amount of magnetite. The pyrrhotite and chalcopyrite occur chiefly in the massive aggregation but they have no value from an

(1) 長門國美禰郡於福村寶鑛山. (2) 入水.

economical stand-point at present. The large quantity of pyrrhotite present in the deposit is remarkable suggesting that the ore minerals were deposited at high temperatures.

The silicate minerals found in the deposit are vesuvianite, wollastonite, amphibole and calcite only.

The vesuvianite occurs along the boundary line between the brecciated fragments of limestone and metallic ore forming a perfect prismatic crystal with a yellowish colour. Sometimes veinlets of vesuvianite penetrate the wollastonite mass which is the earliest product of metasomatism by the hydrothermal solution on the original limestone.

Some amphibole is also developed along the boundary line of limestone fragments. It is of a fine long prismatic form showing a greenish colour. The extinction angle is nearly twenty degrees and the basal sections are also predominantly developed under the microscope. (Pl. XVIII, Fig. 1).

Predominant ore, pyrrhotite, occurs as massive forms along the brecciated zone. The mineral is generally penetrated by veins or veinlets of chalcopyrite.

The genesis of the Takara deposit is due to metasomatism on a limestone fragment in the brecciated zone of highly heated metamorphosing solutions which ascended along the fault line. It is probable that the deposit was formed at considerably high temperatures as shown by the many minerals present.

V. CONCLUSIONS AS TO THE GEOLOGICAL HISTORY AND THE GENESIS OF THE ORE DEPOSITS OF THE OFUKU MINING DISTRICT

The geological history of the Ofuku mining district began with the deposition of a series of Palaeozoic formations represented by the alternation of limestone, sandstone and chert. The numerous fossil remains in the limestone indicate that the formation is distinctly referable to the period from the Carboniferous to the Upper Permian.

The great tectonic movements such as faulting, folding and reversing of the sedimentaries are believed to have taken place at the end of the Palaeozoic age.

The Palaeozoic formation is covered unconformably by the Rhaetic formation which is composed of the alternation of shale, conglomerate, fossiliferous sandstone and thin coal seams. At the end of the

Mesozoic age the fore-mentioned two formations were invaded by a large diorite mass and many porphyrite dikes which seem to be contemporaneous with and genetically related to the associated diorite mass.

This is the most important geological event for the many ore deposits in the district have a close relation to the hydrothermal solution which accompanied the intrusions of these igneous rocks.

Of the post-Mesozoic age, there is no geological record in the district except some alluvial deposits, which cover certain areas of the erosion remains of the Palaeozoic and Mesozoic formations.

The many metallic ores and silicate minerals of contact metamorphic origin in the district, were generally deposited in the limestone layers, near or along the igneous bodies. Occasionally, owing to the great fluidity of the metamorphosing solutions these minerals were carried vertically to a considerable distance from the main body of the intrusions.

Throughout the district, chalcopyrite, pyrite, pyrrhotite and magnetite were commonly associated with large amounts of many silicates such as wollastonite, garnet, diopside and other skarn-forming minerals, as essentially constant compounds and products of igneous metamorphism, though sometimes they show more or less local difference.

As to the genesis of the minerals of contact origin, there is no reason to doubt that the chief elements composing the skarn minerals and the entire metallic ores have been derived from the emanations of the igneous magma except the lime which originated from the limestone, for the limestone is pure calcium carbonate and almost free from impurities.

These minerals in the contact zones show that the silica, alkali, sulphide of copper and iron have been present in the highest degree of concentration in the solutions. Judging from the paragenesis of these minerals, the general sulphide ores were formed immediately after the silicate minerals.

It is remarkable that the many contact metamorphic ore deposits located in numerous places in the district, should have formed at approximately the same geological age, the late Mesozoic period which is regarded as one of the most important metallogenetic epochs in Japan and the neighbouring continent.

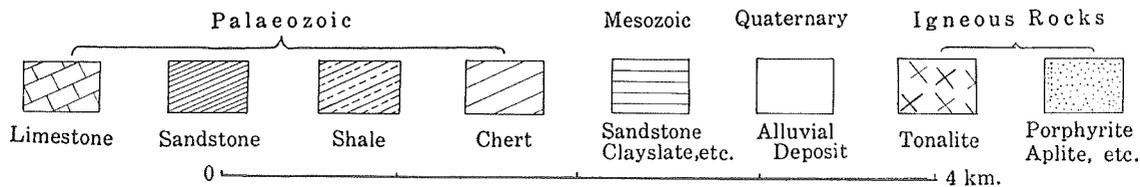
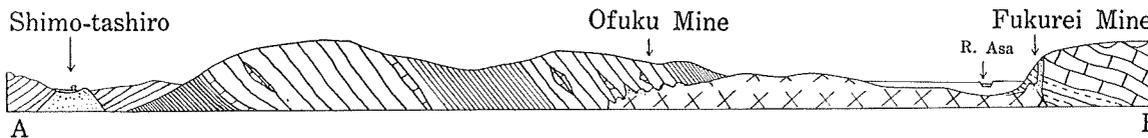
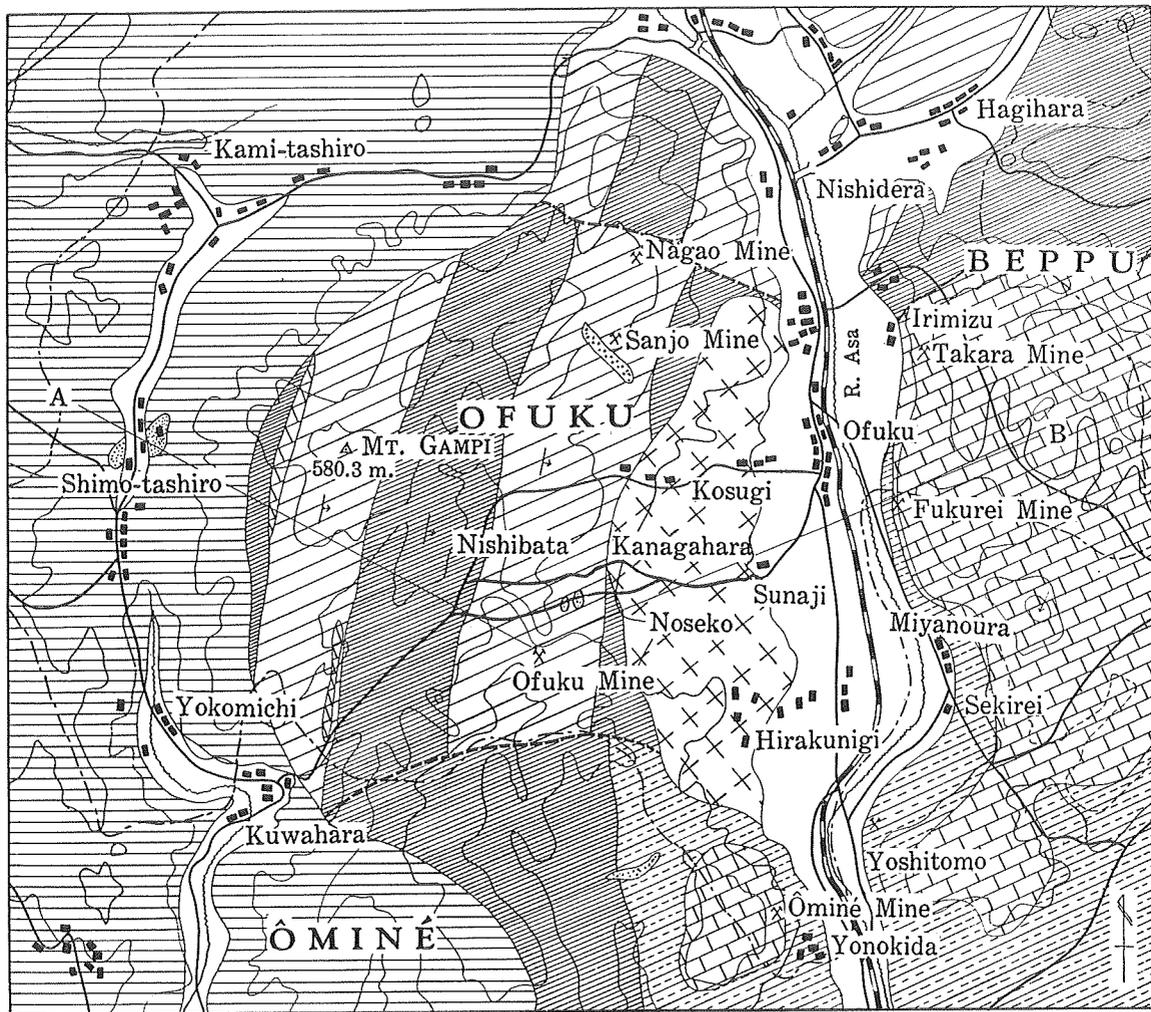
Department of Geology and Mineralogy, Faculty of Science,
Hokkaido Imperial University, Sapporo.

Plate XI

PLATE XI

Geological map of the Ofuku mining district.

GEOLOGICAL MAP OF THE OFUKU MINING DISTRICT.



Takeda del.

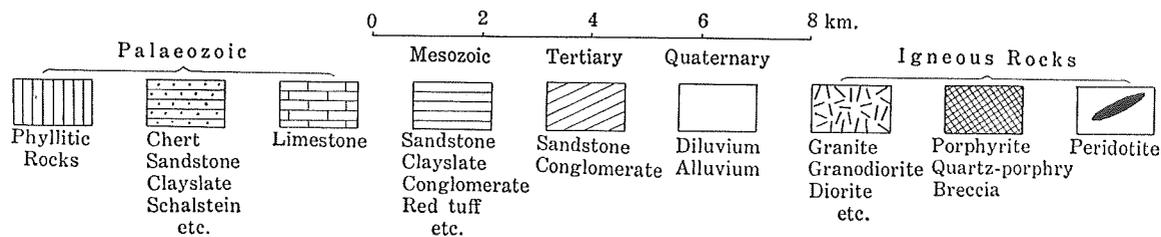
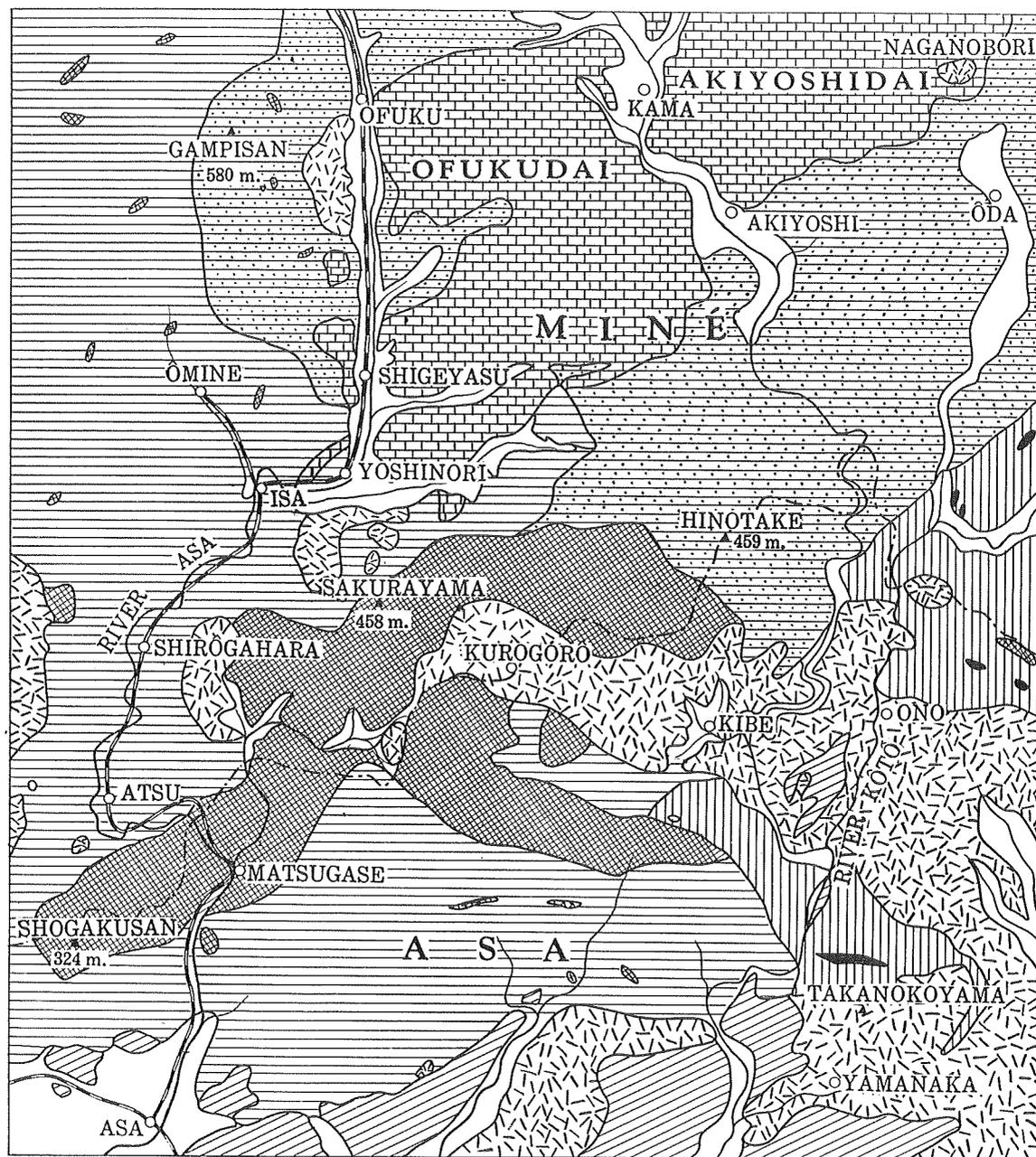
J. Suzuki: Contact Deposits of the Ofuku Mining District.

Plate XII

PLATE XII

Sketch map to show the geology of the region along the Asa and Kôtô rivers.

SKETCH MAP TO SHOW THE GEOLOGY OF THE REGION ALONG
THE ASA AND KÔTÔ RIVERS. (AFTER T. OGURA & T. SUZUKI)



Toriki del.

J. Suzuki: Contact Deposits of the Ofuku Mining District.

Plate XIII

PLATE XIII

Fig. 1. View of the Ofuku Mine as seen from south-east.

Fig. 2. Distant view of the Ofuku Mine as seen from Noseko.

Fig. 3. Leucocratic dykes in the Palaeozoic shale at a rail-road cut near Yonokida.



Fig. 1.



Fig. 2.

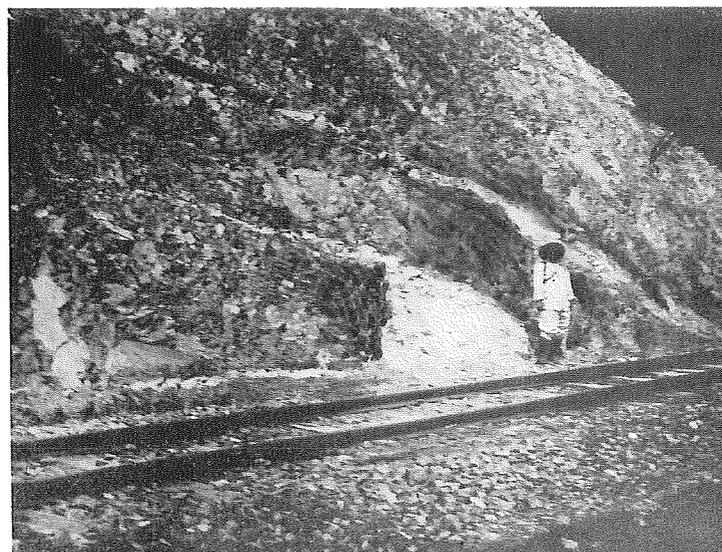


Fig. 3.

Plate XIV

PLATE XIV

- Fig. 1. A = *Fusulinella bocki* Möller. B = *Staffia* sp.
Loc. Isa-mura. Magnified 15 diameters.
Age: Moscovian (Middle Carboniferous).
- Fig. 2. A = *Fusulina crassiseptata*, Deprat.
B = *Neoschwagerina craticulifera* (Schwager).
Loc. Shiraiwa, Ominé-mura. Magnified 6 diameters.
Age: Permian.
- Fig. 3. Metamorphosed chert. Loc. Ofuku mine. Nicols crossed.
Magnified 20 diameters.
- Fig. 4. Hornfels. Loc. Yonokida, Ordinary light. Magnified 20 diameters.
B = Minute flakes of biotite.
- Fig. 5. Wollastonite cluster (W), developing along the cracks in the metamorphosed
chert (c). Loc. Ofuku mine. Ordinary light. Magnified 20 diameters.
- Fig. 6. Biotite-quartz-diorite (Tonalite).
Loc. Kanagahara. Ordinary light. Magnified 20 diameters.
F = Feldspar; H = Hornblende; Q = Quartz; B = Biotite.



Fig. 1.



Fig. 2.

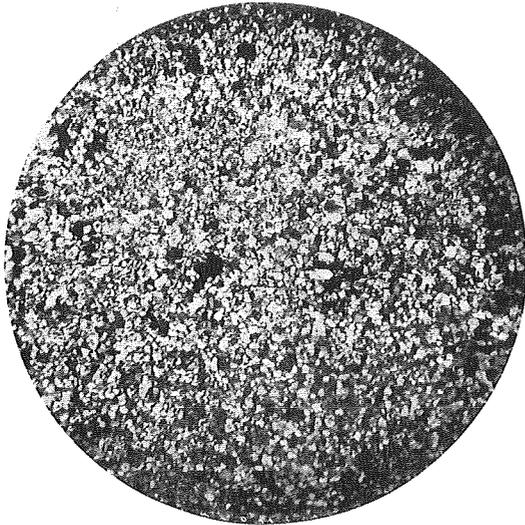


Fig. 3.

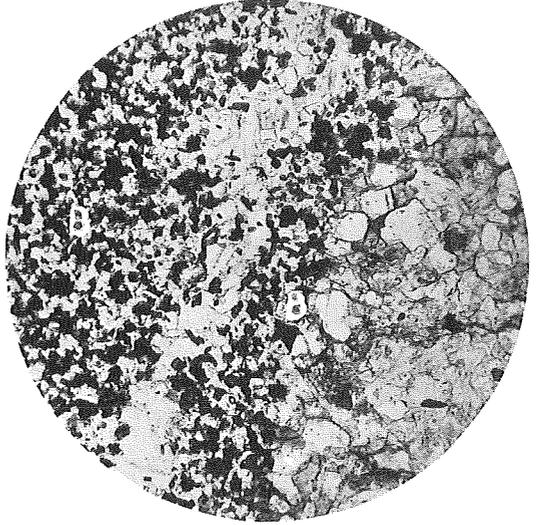


Fig. 4.

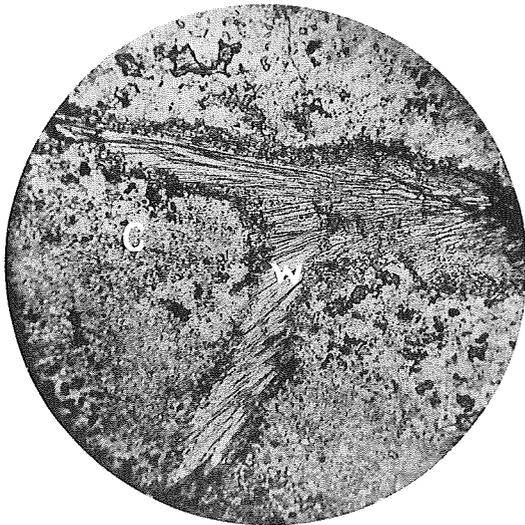


Fig. 5.

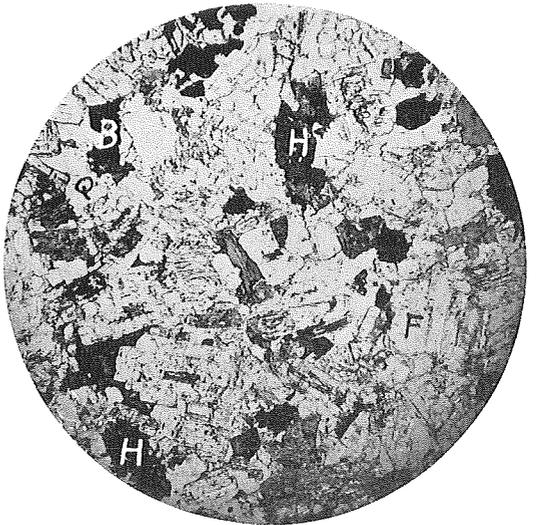


Fig. 6.

Plate XV

PLATE XV

- Fig. 1. Granodiorite. Loc. Yonokida. Ordinary light. Magnified 20 diameters.
F = Feldspar; H = Hornblende; Q = Quartz; B = Biotite.
- Fig. 2. Granite. Loc. Yonokida. Ordinary light. Magnified 20 diameters.
F = Feldspar; Q = Quartz; B = Biotite.
- Fig. 3. Porphyrite. Loc. Sanjô mine. Nicols crossed. Magnified 40 diameters.
F = Feldspar; H = Hornblende.
- Fig. 4. Diopside-titanite-diorite-porphyrite.
Loc. Fukurei mine. Ordinary light. Magnified 40 diameters.
D = Diopside; T = Titanite; F = Feldspar; A = Apatite.
- Fig. 5. Aplitic leucocrate. Loc. Ofuku mine. Ordinary light.
Magnified 40 diameters.
Q = Quartz; F = Feldspar; B = Biotite.
- Fig. 6. Wollastonite (W) and garnet (G) in Calcite (C).
Loc. Ofuku mine. Ordinary light. Magnified 40 diameters.

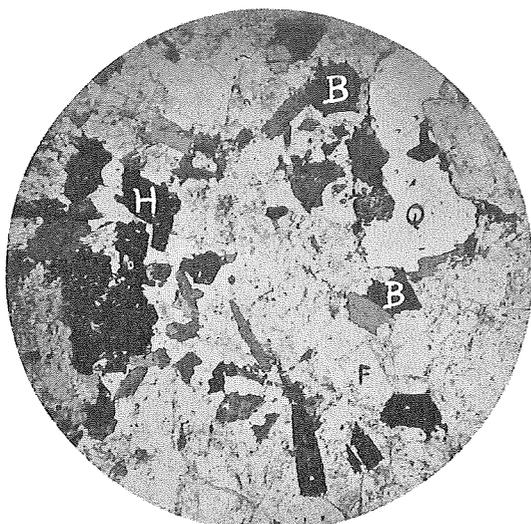


Fig. 1.

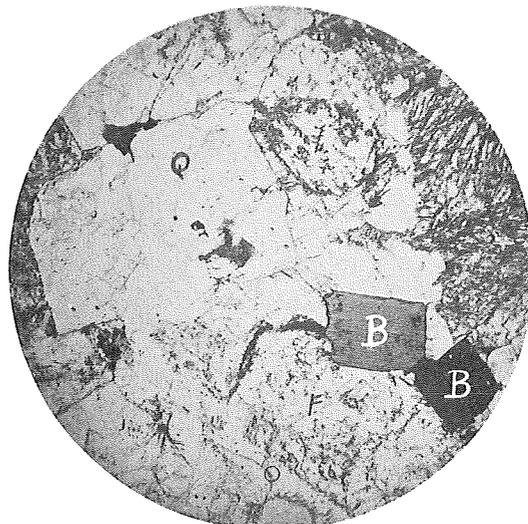


Fig. 2.

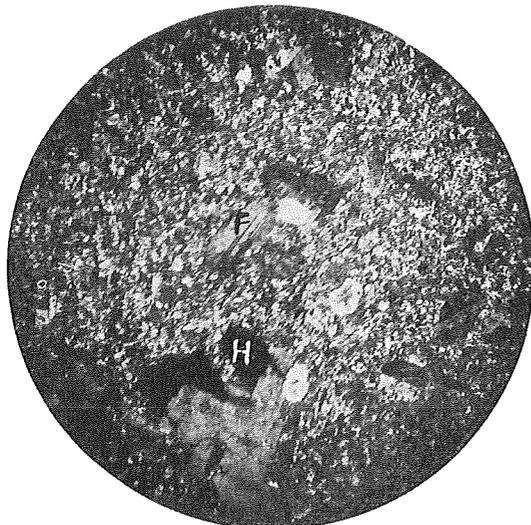


Fig. 3.

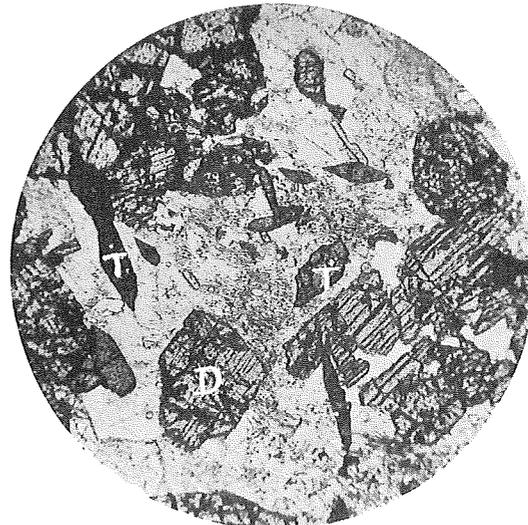


Fig. 4.

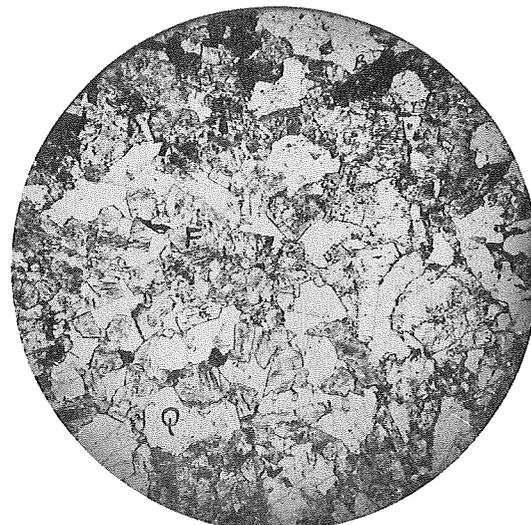


Fig. 5.

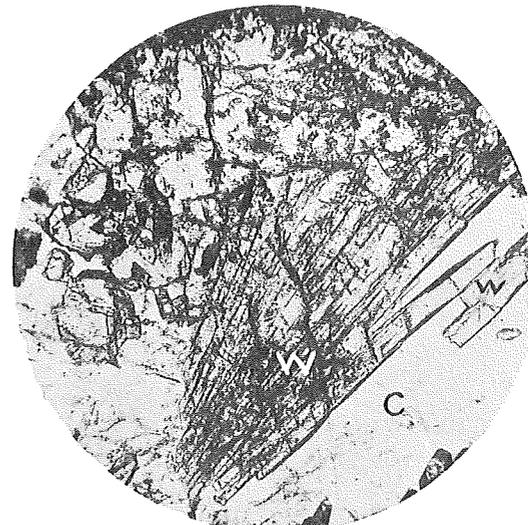


Fig. 6.

Plate XVI

PLATE XVI

- Fig. 1. Wollastonite skarn (W) with vesuvianite (V).
Loc. Ofuku mine. Ordinary light. Magnified 50 diameters.
- Fig. 2. Wollastonite skarn (W) with andradite (G).
Loc. Ofuku mine. Ordinary light. Magnified 20 diameters.
- Fig. 3. Andradite crystal showing optic anomaly.
Loc. Ofuku mine. Nicols crossed. Magnified 50 diameters.
- Fig. 4. Garnet skarn (G). The interspaces of garnet crystals are filled up with quartz (Q) and chlorite (Ch).
Loc. Ofuku mine. Ordinary light. Magnified 20 diameters.
- Fig. 5. Hedenbergite skarn (H).
Loc. Ofuku mine. Ordinary light. Magnified 20 diameters.
- Fig. 6. Diopside skarn.
Loc. Ofuku mine. Ordinary light. Magnified 20 diameters.



Fig. 1.



Fig. 2.

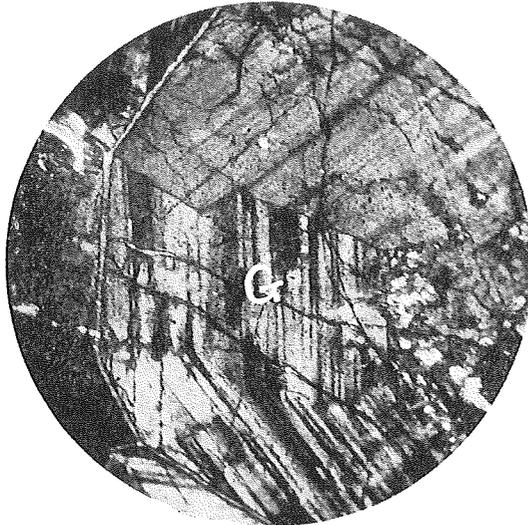


Fig. 3.

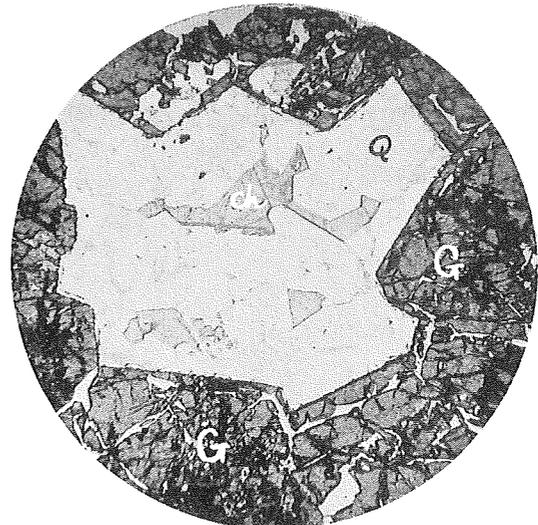


Fig. 4.

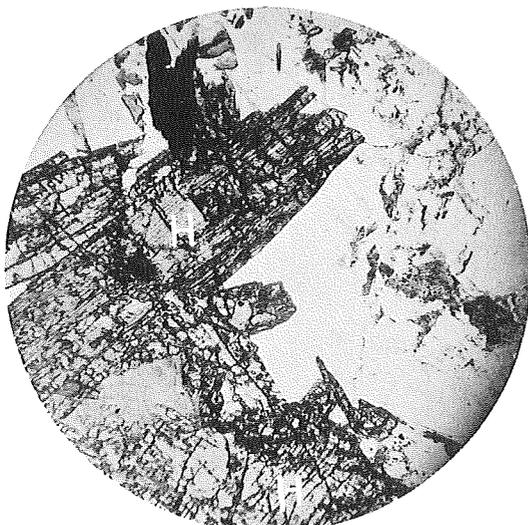


Fig. 5.

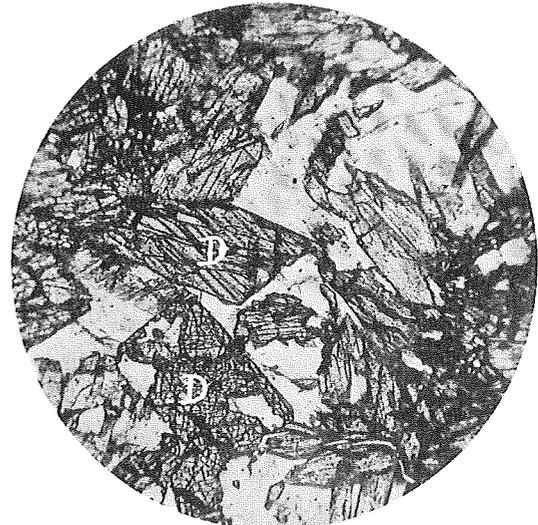


Fig. 6.

Plate XVII

PLATE XVII

- Fig. 1. Diopside skarn (D) with lievrite (L).
Loc. Nagawo mine. Ordinary light. Magnified 20 diameters.
- Fig. 2. Biotite (B) and Garnet (G) in calcite (C).
Loc. Ofuku mine. Ordinary light. Magnified 50 diameters.
- Fig. 3. Specimen of lievrite (L) from the Nagawo deposit.
- Fig. 4. Metamorphosed chert (G) penetrated by the veinlets of quartz (Q).
Ch = chalcopyrite; S = Sericite. Nicols crossed.
Loc. Ofuku mine. Ordinary light. Magnified 20 diameters.
- Fig. 5. Epidote (E) in Calcite (C). Q = Quartz; Ch = Chlorite.
Loc. Ofuku mine. Ordinary light. Magnified 50 diameters.

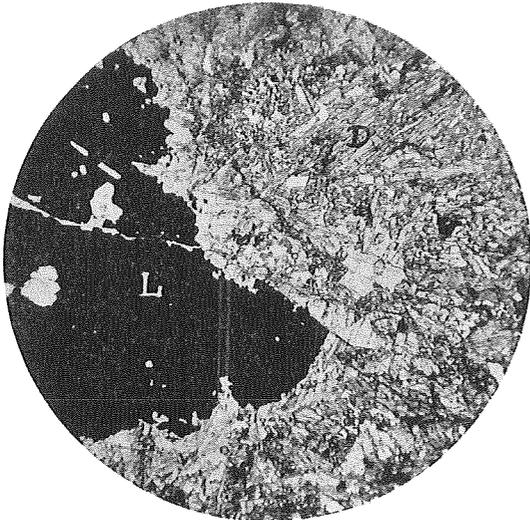


Fig. 1.



Fig. 2.

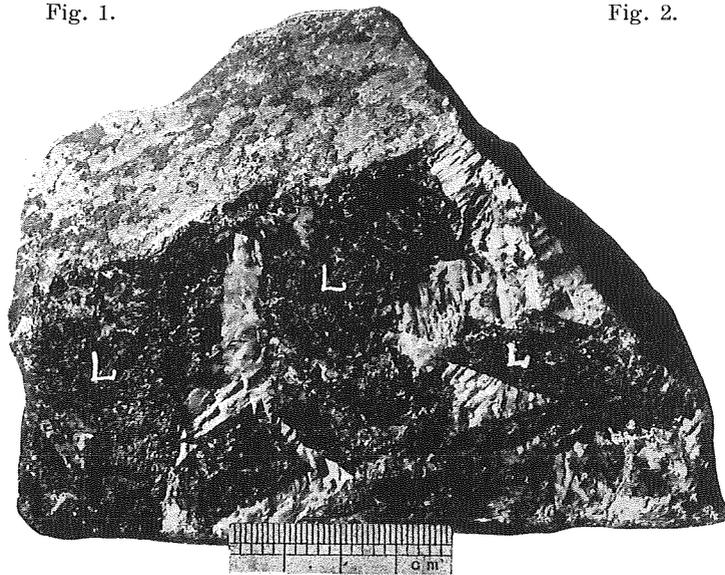


Fig. 3.

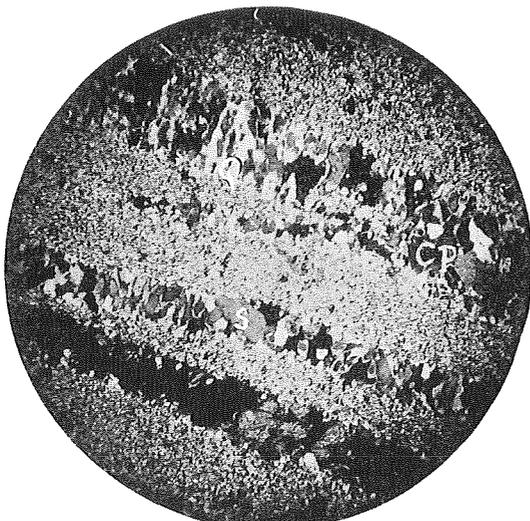


Fig. 4.

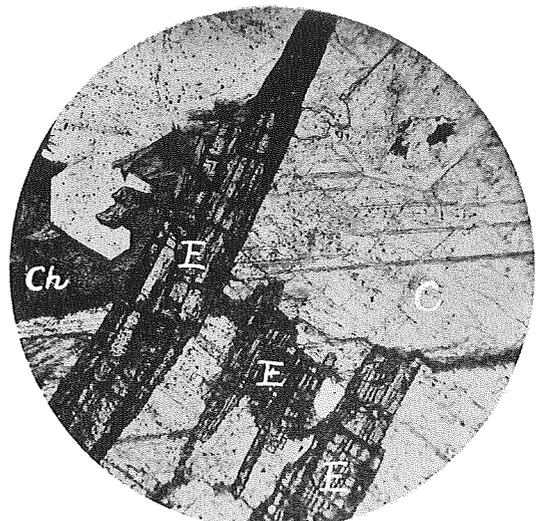


Fig. 5.

Plate XVIII

PLATE XVIII

- Fig. 1. Amphibole skarn (A) in saccharoidal limestone (L) from the Takara deposit. Ordinary light. Magnified 50 diameters.
- Fig. 2. Aggregation of the crystals of scheelite (S), molybdenite (M) and chalcopyrite (Ch) in Quartz (Q).
Loc. Ofuku mine. Ordinary light. Magnified 50 diameters.
- Fig. 3. Magnetite ore from the Fukurei deposit.
M = Magnetite; Cp = Chalcopyrite; C = Calcite; G = Garnet.
- Fig. 4. Chalcopyrite (Cp) ore, penetrated by veinlet of pyrrhotite (Py).
Loc. Ofuku mine. Reflected light. Magnified 50 diameters.
- Fig. 5. Magnetite ore (M) penetrated by veinlet of chalcopyrite (Cp).
Loc. Fukurei mine. Reflected light. Magnified 50 diameters.

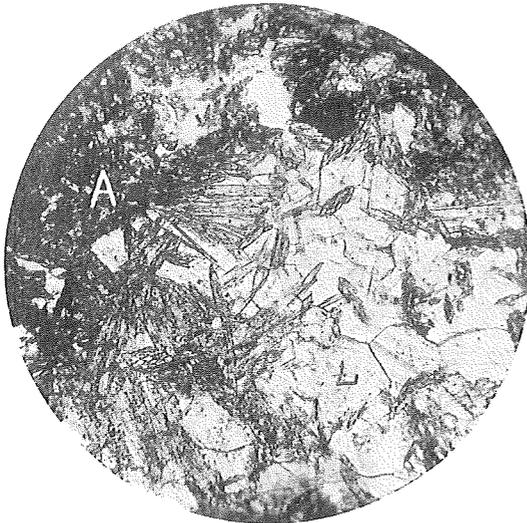


Fig. 1.

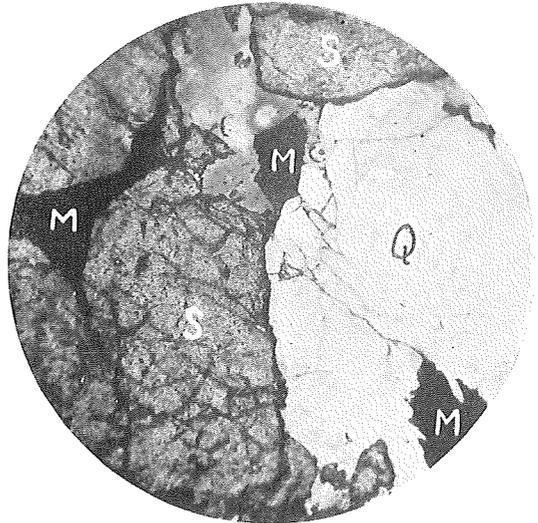


Fig. 2.

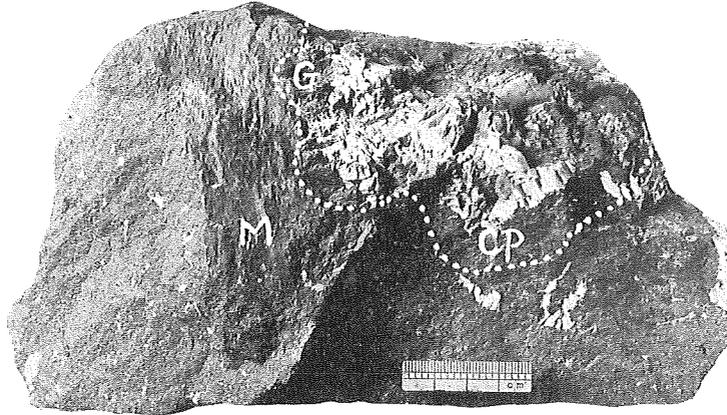


Fig. 3.

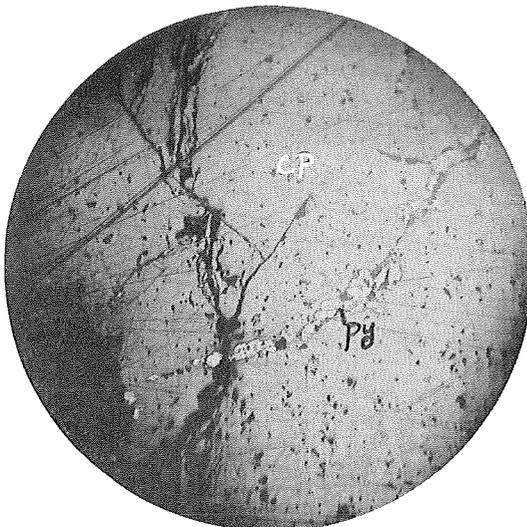


Fig. 4.

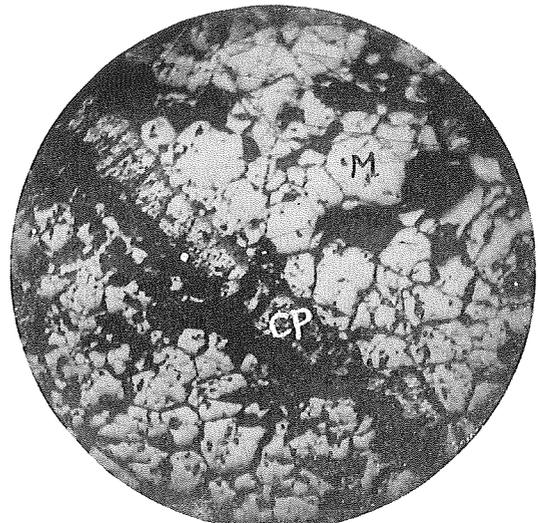


Fig. 5.

Plate XIX

PLATE XIX

- Fig. 1. Specimens of scheelite (S) and secondary tungsten mineral (T) associated with quartz (Q).
Loc. Ofuku mine.
- Fig. 2. Specimens of metamorphosed chert (C) replaced by wollastonite.
Loc. Ofuku mine.
- Fig. 3. Brecciated limestone (L) and shale (S) both partly replaced by chalcopyrite (Cp) and other silicate minerals (Sl).
Loc. Takara deposit.

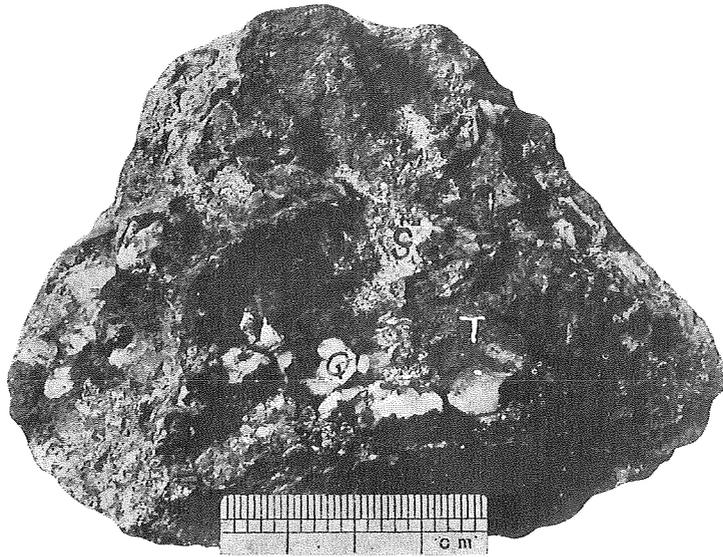


Fig. 1.

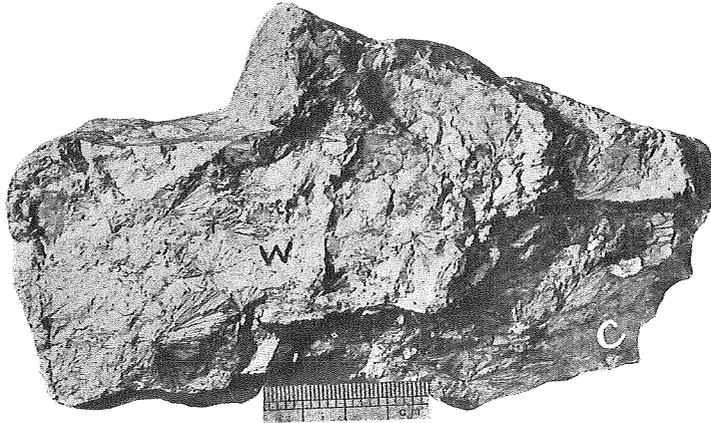


Fig. 2.

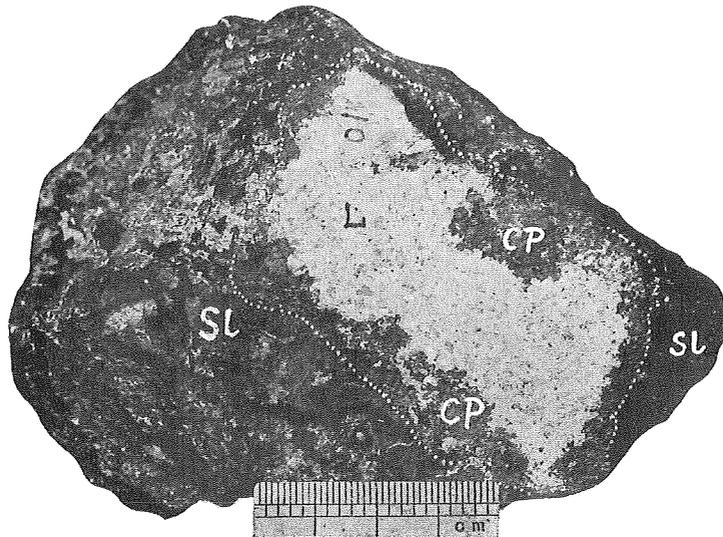


Fig. 3.

Plate XX

PLATE XX

- Fig. 1. Wollastonite-fels (W) penetrated and replaced by vesuvianite (V) and garnet-diopside-skarn (G).
Loc. Ofuku mine.
- Fig. 2. Specimen of wollastonite-fels (W) penetrated by chalcopyrite (Cp) and quartz veinlets (Q).
Loc. Ofuku mine.
- Fig. 3. Specimen of cuprite (Cu), malachite (M) and chrysocolla (Ch).
Q = flinty quartzite.
Loc. Ofuku mine.

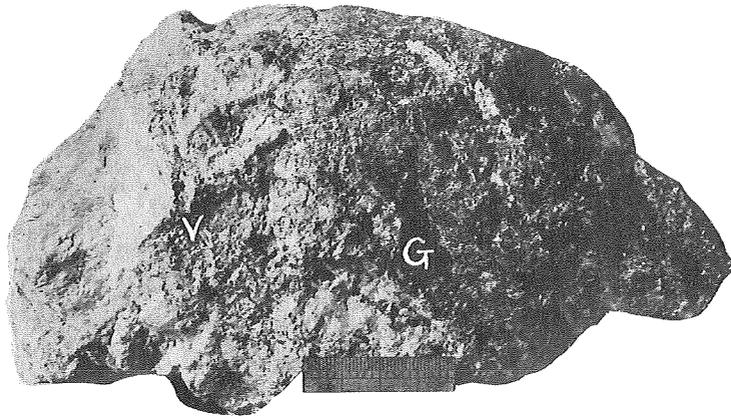


Fig. 1.

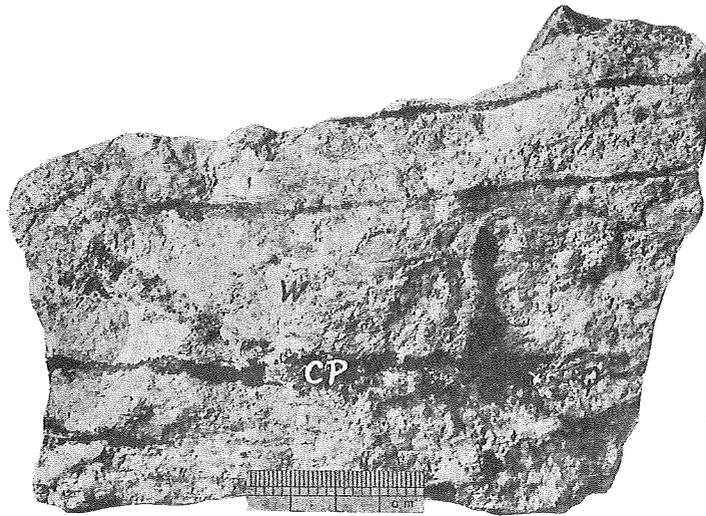


Fig. 2.

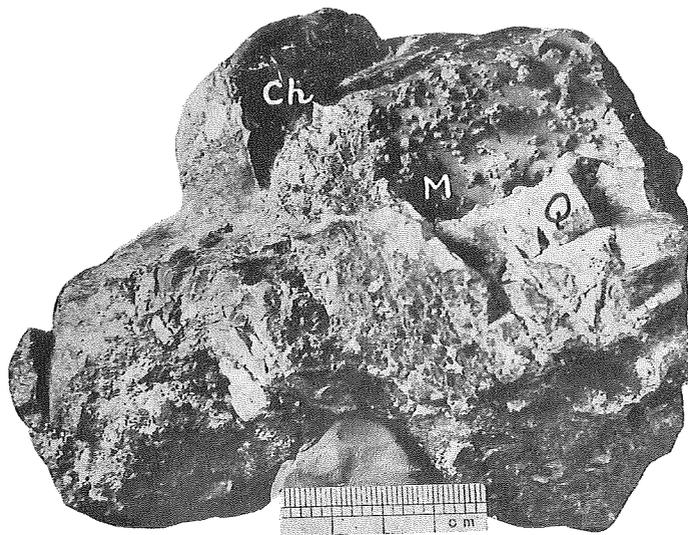


Fig. 3.