Studies on the Molybdenum Deposits of the Daito District, Shimane Prefecture, Japan

By

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The molybdenum deposits of the Daito district are located about 20 Km southwest of Matsue city, Shimane prefecture, Chugoku province. The deposits under consideration are veins of mesothermal type, and now the most productive deposits of molybdenum in Japan. They are believed to have been formed in close relation to the granites distributed widely in this mining district.

Molybdenite and quartz are principal vein minerals, but small amounts of biotite, plagioclase, adularia, epidote, galena, sphalerite, pyrite, calcite, and ankerite are also identified as accessory minerals.

Wall-rock alteration is generally remarkable. It is characterized by the presence of an orderly arrangement of silicified zone, sericitized zone, and chloritized zone, from the inner side to the outer side of the ore veins.

(I) Introduction

In the Chugoku province, there are a number of tungsten and molybdenum deposits closely associated with the igneous activities of the granitic rocks ranging in age from late Mesozoic to early Tertiary. The tungsten deposits are said to have occurred principally in the region of the granite of Hiroshima type and the molybdenum deposits, on the other hand, commonly in the region of the granite of San-in type. The granite of Hiroshima type crops out widely in the Sanyo district, and that of San-in type in the San-in district, the southern part and the northern part of the same province, respectively.

The molybdenum deposits under consideration are situated in the neighborhood of Daito town, Shimane prefecture. In this area, several molybdenum mines such as the Daito, the Seikyu, and the Higashiyama mine have been worked on a large scale since prewar days, and are now foremost in the molybdenum production in Japan.

In the Daito district, there are found various types of the igneous rocks that have intruded in succession but in different stages, together with some

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related metamorphic rocks. These geological situations may suggest that it is very interesting from the points of view of both petrology and economic geology to investigate the problems of origin and localization of the ore deposits in this mining district.

As to geology and ore deposits in the vicinity of the Daito district, some valuable reports have already been published by such workers as Kinosaki[1] (1952), Yamamoto[2] (1954) and others, but all problems have not necessarily been brought out enough. From this point of view, the present authors have attempted to clarify these problems in detail since 1960, as a part of the systematic study entitled, "On the ore deposits associated with the granitic rocks in the Chugoku district".

In the present work, the emphasis is placed on the relationships between the molybdenum deposits and the granite intrusives in the light of additional informations based on the field observation as well as laboratory work. The results obtained by the present authors are mostly in accordance with those of the preceding workers, however, some are not in agreement; namely the age relations among several intrusive rocks, and also the relation of the igneous rocks to the ore deposits.

Both the filling temperature of the liquid inclusions found in quartz and the distribution of the minor elements contained in quartz and molybdenite taken from the molybdenum deposits in this district will be discussed in the next paper.

The sincere thanks of the authors are extended to all members of the above-mentioned mines for their kind instruction and help in the field work. The authors also wish to express their cordial thanks for the Grant from the Scientific Research Fund of the Ministry of Education which enabled them to defray partly their field and laboratory expenses.

(II) Brief Notes on the Molybdenum Deposits in Japan

According to the references[3] already published, major molybdenum provinces in Japan are Kitakami province, northern Abukuma province, Uetsu province, Shirakawa province, Tozukawa province, and Shimane province. These deposits are pegmatitic to hypothermal, and commonly network veins and dissemination, but sometimes pyrometasomatic.

Although the definite age of molybdenum deposits is not yet known, it is said, from the geological evidences, to be probably Cretaceous in Kitakami, northern Abukuma, Tozukawa, and Shirakawa provinces and early Paleogene in Uetsu and Shimane provinces.

The deposits of the Hirase mine, Shirakawa province, occur in granite, and molybdenite ore is associated with small amounts of pyrite and rarely sphalerite and native bismuth. The deposits are quartz veins ranging in part to pegmatitic facies, while in other parts accompanied by the hydrothermal alteration of wall rocks. Sato and Takahashi[4] (1956) described the molybdenite mineralization in the green tuff formation (Miocene in age), in Iwate prefecture. These deposits are considered to be of the epithermal type that occurs at shallow depth. Tsuboya and Ishihara[5] (1958) investigated the tungsten and molybdenum deposits of the Komaki mine, Shimane prefecture. According to them, these deposits are one of the pneumatolytic to hypothermal deposits which have been found to contain radioactive minerals. The main ore minerals are wolframite, sheelite, and molybdenite, together with bröggerite, magnetite, chalcopyrite, pyrrhotite and pyrite. Sato and Kadota[6] (1961) studied the uraniferous molybdenum deposits of the Takane mine, Niigata prefecture, where molybdenite mainly occurs in the druses of granitic pegmatite and also in quartz veinlets filling the irregular fissures in an aplite mass. Pyrite is found in small amounts.

Compared with those mentioned above, the deposits of the Daito district may be unique in that ; (i) the only ore mineral is molybdenite, (ii) the deposits are of mesothermal type, (iii) the deposits are the largest in scale.

(III) Geology

(A) General statement

The Daito district is situated about 20 Km southwest of Matsue city, Shimane prefecture (Fig. 1).

The geology of the area comprises some intrusive and extrusive rocks, and also some related contact metamorphic rocks. The extrusive rocks chiefly occupy the eastern part, whereas the intrusives the western part of the area, and thus they form characteristic topographic features. Namely, the topography of the east side shows a high relief contrasting to that of the west side. The highest mountain in the area is Mt. Seikyu, reaching about 565 m above sea level, and from there the high ridge extends eastwards.

The type locality and distribution of the predominant rocks in this area, clarified by the present authors in the field and petrographical studies, are as follows (Fig. 1, 2, Table 1). They are :

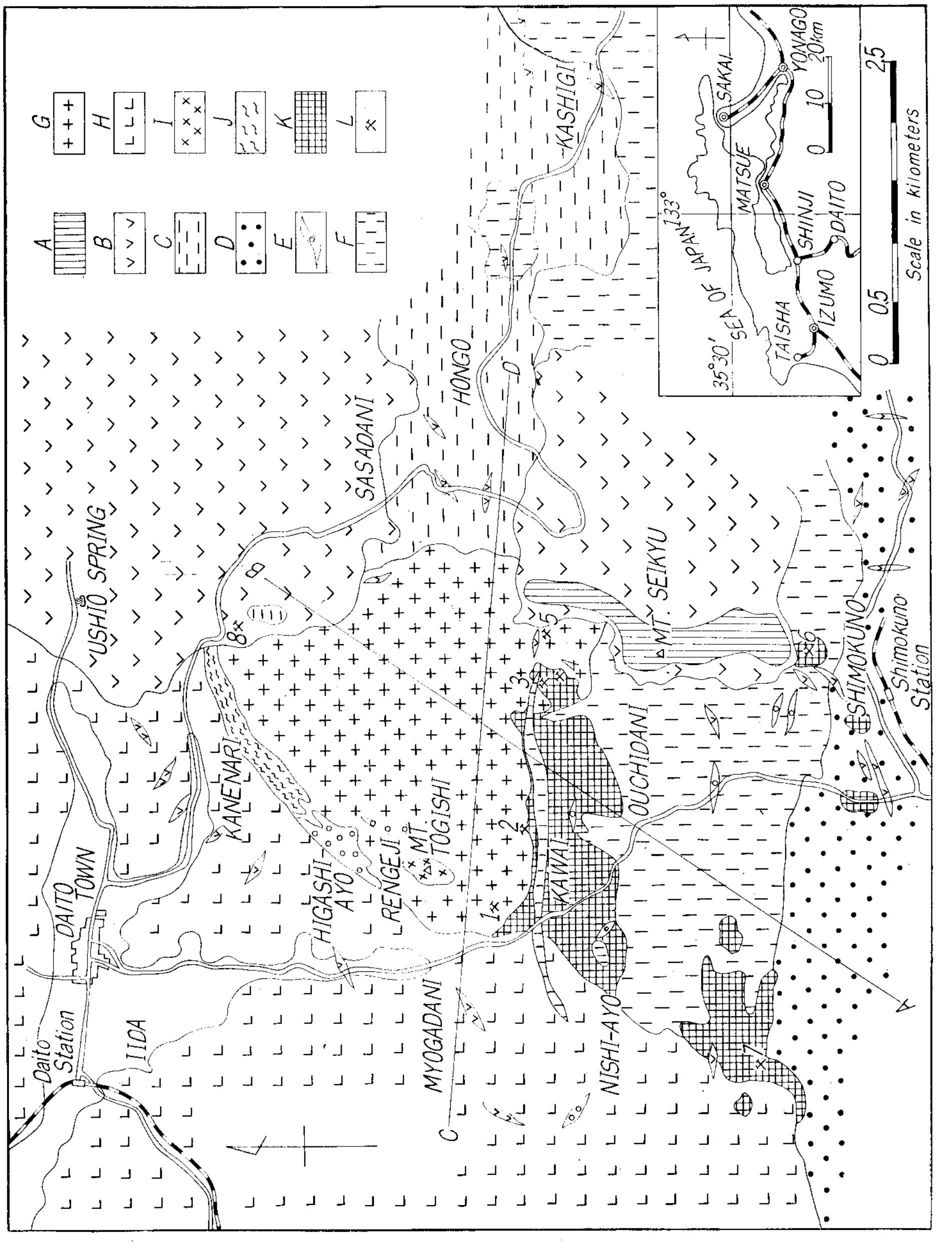


Fig. 1. Geological Map of the Daito Mining District.
A : Seikyu quartz diorite, B : Sasadani andesite, C : Hongo quartz porphyry, D : Shimokuno aplite, E : Aplite dike, F : Ouchidani granite, G : Rengeji granite, H : Daito granodiorite, I : Togishiyama granite, J : Kanenari hornfels, K : Kawai hybrid, L : Locality of ore deposits, 1 ; Honko deposit, Daito mine, 2 : Hinotani deposits, Daito mine, 3 : Honko deposits, Higashiyama mine, 4 : Honko deposits, Seikyu mine, 5 : Namera deposits, Seikyu mine, 6 : Minamiko deposits, Seikyu mine, 7 : Saseko deposits, 8 : Kamitani deposits, Seikyu mine.

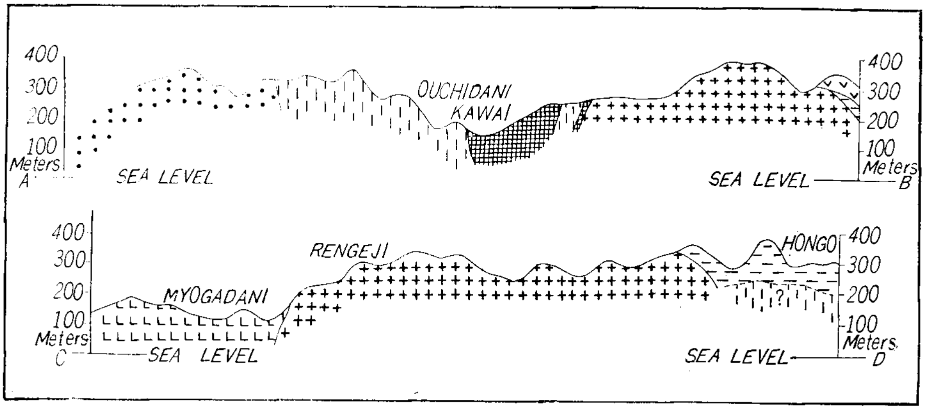


Fig. 2. Geological Cross Sections.
The symbols of the rocks are the same as those of Fig. 1.

Younger group

Seikyu quartz diorite ......is found near Mt. Seikyu.

Sasadani andesite ....covers widely Sasadani and Shinobuchi villages.

Older group

Hongo quartz porphyry ...crops out extending from west to east near Hongo and Kashiki villages.

Shimokuno aplite...............is found widely near Shimokuno village.

Ouchidani granite ....is exposed widely near Ouchidani village.

Rengeji granite..................is found in the central part of the map-area.

Daito granodiorite ....occurs in the western part of the map-area.

Metamorphic rock group

Togishiyama granite ....occurs as a small mass surrounded by the Rengeji granite.

Kawai hybrid ....crops out near Kawai village surrounded by other intrusive rocks.

Kanenari hornfels ....occurs in the narrow zone along the boundary between the Daito granodiorite and the Rengeji granite.

Foot note: Among these rocks, such rocks as Seikyu quartz diorite, Sasadani andesite, Hongo quartz porphyry, Kanenari hornfels, and Togishiyama granite were newly named by Sano[7] (1963), one of the authors, but, for the rest, the common names proposed by Yamamoto[8] (1954) were used so as to avoid the confusions.

Table 1. Rocks occurring in the Daito District and their Component Minerals

	Rock Variety	Occurrence	Principal Constituents	Minor Constituents	Plagioclase Composition
1	Quartz dioritic hybrid Granitic hybrid	—	Hornblende, Biotite Quartz, Plagioclase, Orthoclase	Zircon, Sphene, Apatite Magnetite	An_{32}–An_{42}
2	Hornfels	—	Quartz, Biotite, Plagioclase	—	—
3	Biotite granite	—	Quartz, Plagioclase, Orthoclase Perthitic orthoclase, Biotite	Zircon, Apatite, Sphene Magnetite	—
4	Hornblende biotite granodiorite	Intrusive body	Quartz, Plagioclase, Orthoclase Biotite, Hornblende	Zircon, Sphene, Apatite Magnetite	An_{28}
5	Biotite granite	Intrusive body	Quartz, Plagioclase, Orthoclase Perthitic orthoclase, Biotite	Zircon, Apatite, Sphene Magnetite, Muscovite	An_{14}–An_{27}
6	Biotite granite	Intrusive body	Quartz, Plagioclase, Orthoclase Perthitic orthoclase, Biotite	Zircon, Muscovite Sphene, Magnetite	An_{16}–An_{17}
7	Aplite	Intrusive body	Quartz, Plagioclase, Perthitic orthoclase, Microcline, Biotite	Zircon, Muscovite Magnetite	An_{20}
8	Quartz porphyry Rhyolite	Intrusive body	Quartz, Plagioclase Biotite	Sphene, Zircon Apatite	An_{17}
9	Augite andesite Hornblende andesite Agglomerate Tuff	Intrusive body Lava flow	Augite, Hornblende Plagioclase	Sphene, Pyrite Magnetite	An_{60}–An_{83}
10	Quartz diorite	Intrusive body	Hornblende, Plagioclase, Quartz	Magnetite	An_{68}

1 : Kawai hybrid, 2 : Kanenari hornfels, 3 : Togishiyama granite, 4 : Daito granodiorite, 5 : Rengeji granite, 6 : Ouchidani granite, 7 : Shimokuno aplite, 8 : Hongo quartz porphyry, 9 : Sasadani andesite, 10 : Seikyu quartz diorite.

(B) Description of the rocks

Mode of occurrence and general aspect of the principal rocks cropping out in this mining district are as follows:

(1) *Kawai hybrid*——The kawai hybrid is exposed typically at Kawai village. It occuppies comparatively a narrow belt about 1 Km in width, extending from west to east about 2.5 Km long, and is surrounded by the Daito granodiorite at its west side, by the Rengeji granite at its north side and by the Ouchidani granite at its south side, respectively (Fig. 1).

This hybrid is generally fine-grained and compact in texture and is rather dark in color. It resembles quartz diorite in chemical composition as well as in lithologic character (Fig. 3, Table 1, 2).

Although the original rocks of the Kawai hybrid have not been known, the following field evidences indicate that most of these hybrid may have been derived presumably from the Paleozoic sedimentary rocks by the metamorphic action of the Rengeji granite: (i) Along the contact zone between the Kawai hybrid and the Rengeji granite, the acidic hybrid having the external appearance of fine-grained granite is generally observable. This rock seems to have been derived from the contamination between them. (ii) This geological diagnostic, however, is not recognized anywhere near the contact zone between the Kawai hybrid and the Ouchidani granite. (iii) The very contact between the Kawai hybrid and the Daito granodiorite is not exposed in the field. The original rock of this hybrid, however, seems to have locally been metamorphosed during the intrusion of this granodiorite.

The original rocks of the Kawai hybrid and the Kanenari hornfels (mentioned next) are presumed to be the oldest rocks in this mining district.

Furthermore, some hybrids which resemble the Kawai hybrid in petrographic features are also found in small masses at several localities away from the Kawai village. These rocks may have been derived from the metamorphism by the Ouchidani granite and by the Shimokuno aplite (mentioned next).

The component minerals of the Kawai hybrid together with the other intrusive and extrusive rocks are summarized in Table 1.

In addition, both the Ouchidani granite and the Sasadani andesite are found as the dikes within the Kawai hybrid area.

(2) *Kanenari hornfels*——The distribution of this rock is restricted within the narrow zone (about 1.5 Km long and about 125 m wide) extending from northeast to southwest along the boundary between the Daito granodiorite and

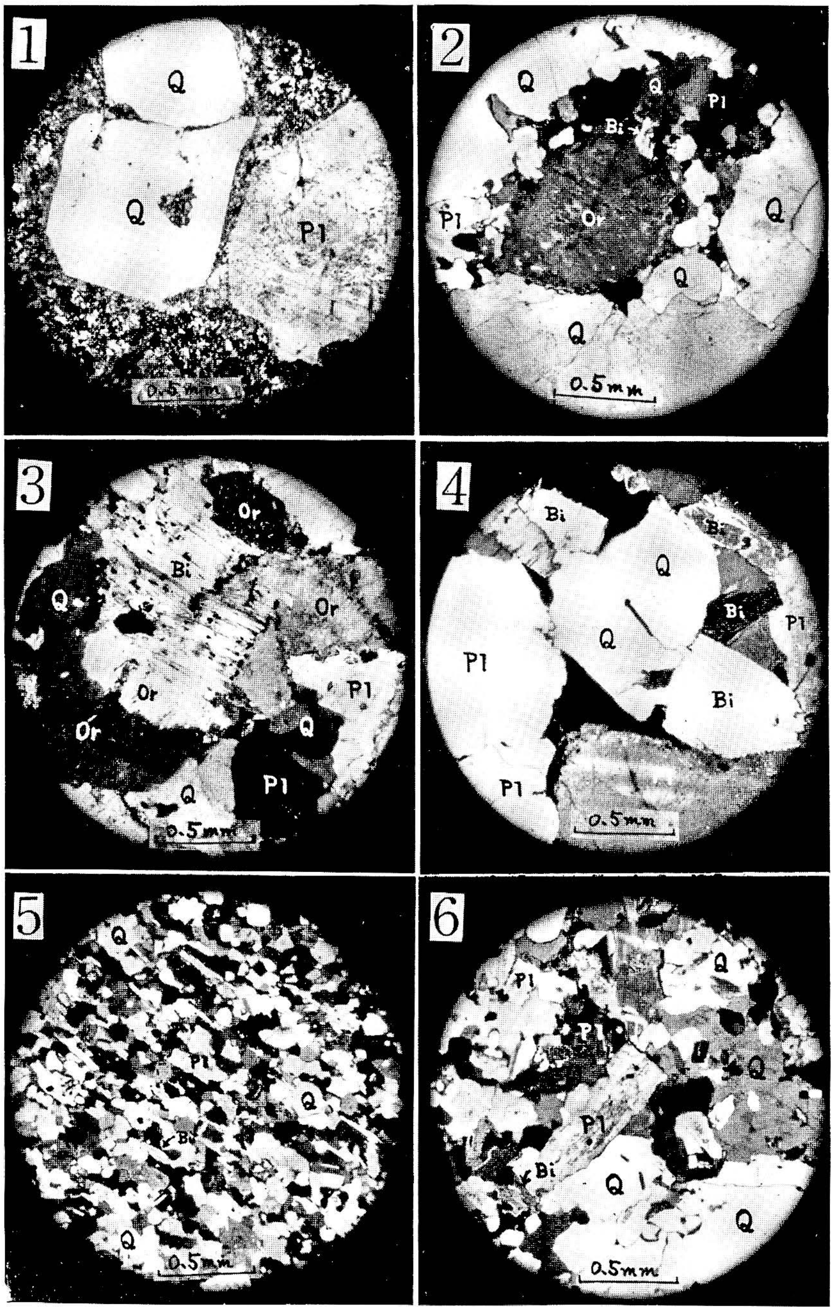


Fig. 3. Photomicrographs of the Principal Rocks.
Photo. 1: Hongo quartz porphyry, Photo. 2: Ouchidani granite, Photo. 3: Rengeji granite, Photo. 4: Daito granodiorite, Photo. 5: Kanenari hornfels, Photo. 6: Kawai hybrid, Q : Quartz, Pl : Plagioclase, Or : Orthoclase, Bi : Biotite.

the Rengeji granite (Fig. 1).

This hornfels is fine-grained and white grayish in color, and contains the microcrystalline quartz grains in considerable amounts, and also biotite and plagioclase in small amounts, so that it is very siliceous in composition (Fig. 3, Table 1). Its original rock is considered to be probably sandstone of the Paleozoic formation.

In the field observations, biotite often exhibits the preferred orientation near the west end of the same hornfels area, but not near its east end (the Kamitani deposits). Therefore, this fact may show that local physical condition prevailed in this particular zone.

(3) *Togishiyama granite*——This rock crops out in Mt. Togishiyama as a small mass enclosed by the Rengeji granite (Fig. 1). At the boundary zone between them, the transitional part in which the former passes gradually into the latter is observable.

Except that the biotite contained in the rock shows somewhat the preferred orientation, this rock is very much similar to the Rengeji granite both in external appearance and in mineral composition (Table 1).

Yamamoto[9] (1954) considered that the Togishiyama granite along with the Rengeji granite may be the oldest in the map-area. However, this concept is not in agreement with the results of the present authors.

Judging from geological evidences mentioned above, it is reasonably considered that the rocks have been derived in situ from the process of granitization of the pre-existing rocks such as the Daito granodiorite and the original rocks of the Kawai hybrid or the Kanenari hornfels during the intrusion of the Rengeji granite magma.

(4) *Daito granodiorite*——This rock is hornblende biotite granodiorite, and found exposed extensively in the western part of the map-area. As already stated, this granodiorite area forms topographically a rather lower relief (altitude is about 200 m±) within the map-area (Fig. 1, 2, Table 1, 2).

In textures, this granodiorite is coarse-grained and equigranular, whereas both the Rengeji granite and the Ouchidani granite (mentioned next) are porphyritic. Thus, the former may represent the more plutonic character in comparison with the latter two (Fig. 3).

In the field, age relations between the Daito granodiorite and the Rengeji granite are not able to be definitely determined because of the fact that the very contact between them is not exposed. However, on the basis of petrographical data, it is presumed that the Daito granodiorite may be older than the Rengeji granite. It is explained in detail in the following paragraph.

Dikes of the Ouchidani granite and the Sasadani andesite intrude this granodiorite in several places. From these results, the Ouchidani granite is younger than this granodiorite.

(5) *Rengeji granite*——This rock is biotite granite and is situated in the central part of the map-area. The topography of this granite area shows by far a higher relief (altitude is 200—300 m) than those of the surrounding areas where the Kawai hybrid and the Daito granodiorite are exposed (Fig. 1, 2, Table 1, 2).

As regards age relation, the following evidences suggest that this granite is younger than the Daito granodiorite. They are:

- (i) This rock is usually fresh compared with the Daito granodiorite.
- (ii) The porphyritic texture is, as a whole, developed throughout this granite, whereas the Daito granodiorite is coarse-grained and equigranular (Fig. 3).
- (iii) Within the Rengeji granite area, it is observable that the rock is coarse-grained in its central part, but is fine- to medium-grained near the boundary with the Daito granodiorite.

Judging from the facts that this rock is one of the most important country rocks of the molybdenum deposits developed in this mining district, and also almost all of the deposits occur near the marginal part of this granite, it is certain that these molybdenum deposits may have close genetic relations with this rock.

In several places, this rock is intruded by the dikes of both the Ouchidani granite and the Sasadani andesite. In addition, many aplite dikes are closely associated with this granite.

(6) *Ouchidani granite*——This rock is biotite granite, and the major part of it is situated adjacent to the south border of the Kawai hybrid area (Fig. 1, 2, Table 1, 2).

As already mentioned, this rock cuts the Daito granodiorite and also the Rengeji granite; so that this rock is youngest among these intrusives. On the other hand, this rock is intruded by the Shimokuno aplite and also by the Sasadani andesite as dikes at peripheral places, and also is covered at its central part by the Sasadani andesite and the Seikyu quartz diorite. Besides these dikes, pegmatites and aplites are also found locally.

The Ouchidani granite is, as a whole, much the same in external appearance as the Rengeji granite, but a detailed examination reveals that the former has more conspicuous porphyritic texture than the latter (Fig. 3). In this rock, the fine-grained minerals (quartz, orthoclase, perthite, and biotite, etc.) are developed in aggregates around the crystals of the coarse-grained minerals (quartz, orthoclase, perthite, and others).

In addition, this rock looks rather pinkish in color due to the presence of the pink feldspars.

Showing the close association with the Ouchidani granite, some hybrids which resemble the Kawai hybrid occur locally in the vicinities of the Saseko deposits and also of the Seikyu-Minamiko deposits. The country rock of these deposits is made up of this hybrid.

These hybrids may have been formed from their original rocks (probably same as those of the Kawai hybrid) by the metamorphism of the Ouchidani granite magma.

From this evidence, it is probable that this granite also has genetically close relation with the molybdenum deposits in this mining district, together with the Rengeji granite as described in the foregoing paragraph.

(7) *Shimokuno aplite*——This rock is light-colored and fine-grained aplite. It occurs principally at Shimokuno village in contact with the south border of the Ouchidani granite area, extending from east to west (Fig. 1, 2, Table 1, 2).

Topographically, this rock area forms a high relief (altitude is about 300–380 m) together with the eastern area which is occuppied by both the Sasadani andesite and the Seikyu quartz diorite (Fig. 2).

The Shimokuno aplite includes locally pegmatite dikes and also small masses of granite which closely resembles the Ouchidani granite in appearance. Furthermore, as previously mentioned, numerous pegmatite and aplite dikes are recognized as well within the Ouchidani granite area.

From this evidence, it is supposed that the Ouchidani granite and the Shimokuno aplite have intruded in nearly the same age closely connected with each other, and resulted in two different rock facies; namely, one is granite, and the other is aplite, respectively.

The hybrid found on the road side leading from Kawai village to Shimokuno village is extremely similar to the Kawai hybrid megascopically as well as optically. This hybrid may have been formed from its original rock by the effects of the Shimokuno aplite magma.

On the east end of the map-area, the Shimokuno aplite shows a porphyritic texture due to the increase of coarse-grained quartz.

In addition, this aplite is intruded by the Sasadani andesite as dikes in several places.

(8) *Hongo quartz porphyry*——This rock is exposed widely in the area east of the Rengeji granite. It consists mainly of quartz porphyry, but, in places, it comprises small masses of both rhyolite and granite porphyry. Indeed,

near Shiota village where this rock comes into contact with the Ouchidani granite, the latter has become more porphyritic in texture, and is gradational into granite porphyry or quartz porphyry (Fig. 1, 2, 3, Table 1).

These geological proofs lead to the suggestion that this quartz porphyry may correspond to the chilled rock facies of the Ouchidani granite which were consolidated at rather shallow depth.

This rock likewise is intruded locally by small dikes of the Sasadani andesite. Within the Sasadani andesite area, on the other hand, this quartz porphyry is exposed as small fenster.

Table 2. Chemical Compositions and Norms of the Principal Rocks

No.	1	2	3	4	5	6	A	B
SiO_2	77.3	74.4	72.3	64.3	70.2	61.9	72.16	72.25
TiO_2	0.65	0.15	0.39	1.25	0.76	1.78	0.35	0.35
Al_2O_3	12.4	14.6	14.8	15.6	14.2	17.3	13.93	14.04
Fe_2O_3	0.30	1.00	1.31	2.32	1.58	1.79	0.49	0.38
FeO	0.36	0.36	1.23	2.66	1.33	4.11	2.23	2.32
MnO	tr.	tr.	tr.	0.05	0.06	0.13	0.26	0.19
MgO	0.44	0.22	0.93	2.80	1.23	1.58	0.63	0.67
CaO	0.54	1.82	1.68	3.63	2.59	3.24	2.02	2.13
Na_2O	3.06	3.30	4.10	3.94	4.19	4.44	3.61	3.43
K_2O	4.37	3.15	3.00	3.96	2.63	1.47	3.23	3.17
H_2O^+	0.08	0.35	0.55	0.39	0.73	1.03	0.62	0.64
H_2O^-	0.18	0.13	0.22	0.21	0.11	0.11	0.19	0.21
P_2O_5	tr.	tr.	0.04	0.13	0.09	0.32	0.28	0.22
Total	99.68	99.48	100.55	101.24	99.70	99.20	100.00	100.00
Sp. Gr.	2.63	2.65	2.67	2.75	2.68	2.77	—	—
Q	38.5	36.7	30.2	14.1	27.2	19.5	32.2	33.3
Or	26.4	19.0	18.0	23.0	16.0	9.0	19.5	18.9
Ab	27.9	30.5	37.0	35.0	38.0	40.9	30.4	28.8
An	3.0	9.5	7.5	13.5	12.0	14.0	8.3	9.7
C	1.7	2.6	2.3	—	0.1	3.8	1.4	1.3
Wo	—	—	—	1.4	—	—	—	—
En	1.2	0.6	2.6	7.8	3.4	4.6	1.6	1.7
Fs	—	—	0.2	0.8	0.2	3.0	3.6	3.7
Mt	0.3	1.0	1.4	2.4	1.6	1.9	0.7	0.7
Il	1.0	0.2	0.6	1.8	1.2	2.6	0.6	0.6
Ap	—	—	0.3	0.3	0.3	0.8	0.7	0.3

1 : Shimokuno aplite, 2 : Ouchidani granite, 3 : Rengeji granite, 4 : Daito granodiorite, 5 : Kawai hybrid (acidic hybrid), 6 : Kawai hybrid (basic hybrid), A : Average composition of the granites associated with the tin deposits of Japan, B : Average composition of the granites in Japan.

(9) *Sasadani andesite*——As already described, this andesite intrudes or covers the other older rocks in this mining district (Fig. 1, 2, Table 1).

Typically, it rests upon the Hongo quartz porphyry, by which its distribution area is divided into two major parts, i. e. the northern and the southern areas.

The Sasadani andesite comprises in part compact hornblende andesite and augite andesite and in part some volcanic pyroclastic rocks such as andesitic agglomerate and tuff, etc. These volcanics are believed to have erupted out and deposited almost simultaneously with each other. They may be considered as belonging to Miocene epoch.

(10) *Seikyu quartz diorite*——This rock is found as the narrow belt elongating from north to south within the Sasadani andesite area. It covers Mt. Seikyu (about 565 m above sea level) which forms the highest peak in the map-area.

This youngest rock intrudes the Sasadani andesite as the dike of irregular shape (Fig. 1, Table 1).

(C) **Chemical compositions of the rocks**

Four specimens of the granitic rocks and two specimens of hybrids were analyzed. The chemical compositions and the values of Norm of these principal rocks are shown in Table 2. On the basis of this data, the following triangular diagrams for (Q+Or)-(Ab+An)-Mf, Q-Or-(Ab+An), Or-Ab-An, were constructed. For reference, the data[10),11)] (average value) for the granites from Japan and the granites associated with tin deposits of Japan were compared. They are all shown in Table 2 and Fig. 4, 5, 6.

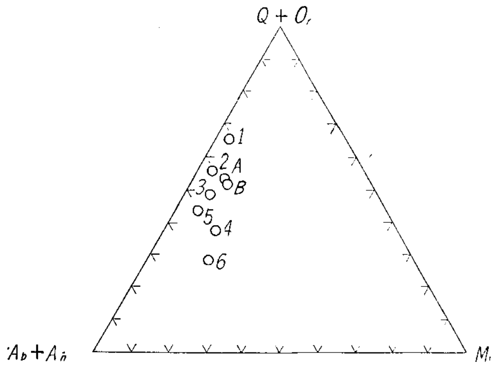


Fig. 4. (Q+Or)—(Ab+An)—Mf Diagram.
1 : Shimokuno aplite, 2 : Ouchidani granite, 3 : Rengeji granite, 4 : Daito granodiorite, 5 : Kawai hybrid (acidic hybrid), 6 : Kawai hybrid (basic hybrid), A : Mean value of the compositions of granites associated with the tin deposits of Japan, B : Mean value of the compositions of granites in Japan, Q : Quartz, Or : Potash feldspar, Ab : Albite, An : Anorthite, Mf : Mafics and minor accessories,

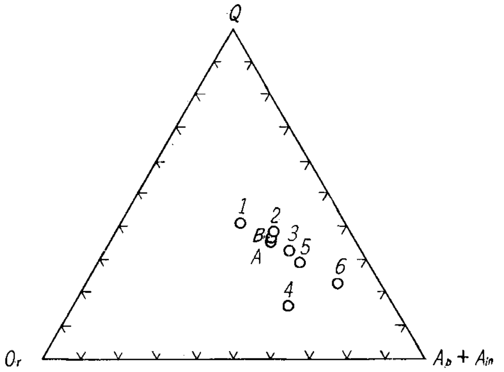


Fig. 5. Q—Or—(Ab+An) Diagram. The symbols are the same as those of Fig. 4.

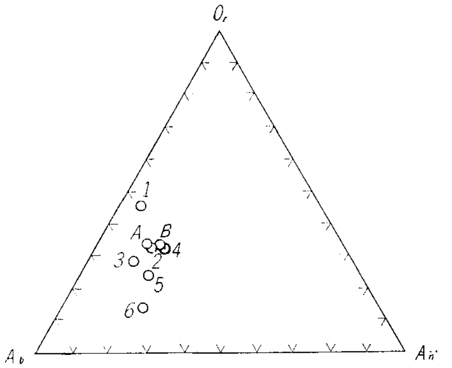


Fig. 6. Or—Ab—An Diagram. The symbols are the same as those of Fig. 4.

(IV) Ore Deposits

(A) General statement

Main ore deposits now in operation in this mining district are Honko deposits of the Higashiyama mine, Honko deposits of the Seikyu mine, and Honko and Hinotani deposits of the Daito mine.

Some deposits such as Namera, Kamitani and Minamiko of the Seikyu mine are not worked at present. The Saseko deposits were abandoned long ago (Fig. 1).

The deposits which are situated in the peripheral zone of the Rengeji granite are all molybdenite quartz veins. They are reasonably believed to have been formed by the post-igneous action of this granite. Both Seikyu-Minamiko and Saseko deposits, on the other hand, have genetic relations with the Ouchidani granite. Besides, the hybrids found here and there in the map-area are regarded to have also close relations with the deposits; they played an important role as the cap-rocks which control structurally the emplacement of ore deposition.

(B) Description of the ore deposits

(1) *Honko deposits of the Higashiyama mine*——As shown on the underground geological map, ore veins of these deposits are mainly developed near the contact between the Rengeji granite and the Kawai hybrid (Fig. 7).

This contact area consists of four rock varieties such as the Rengeji granite, the aplite (locally porphyritic granite), the acidic hybrid, and the Kawai hybrid (so-called basic hybrid), arranged from east to west. The Rengeji granite passes gradually into aplite or porphyritic granite, and the intermediate narrow zone between the second and the fourth rocks is occup-

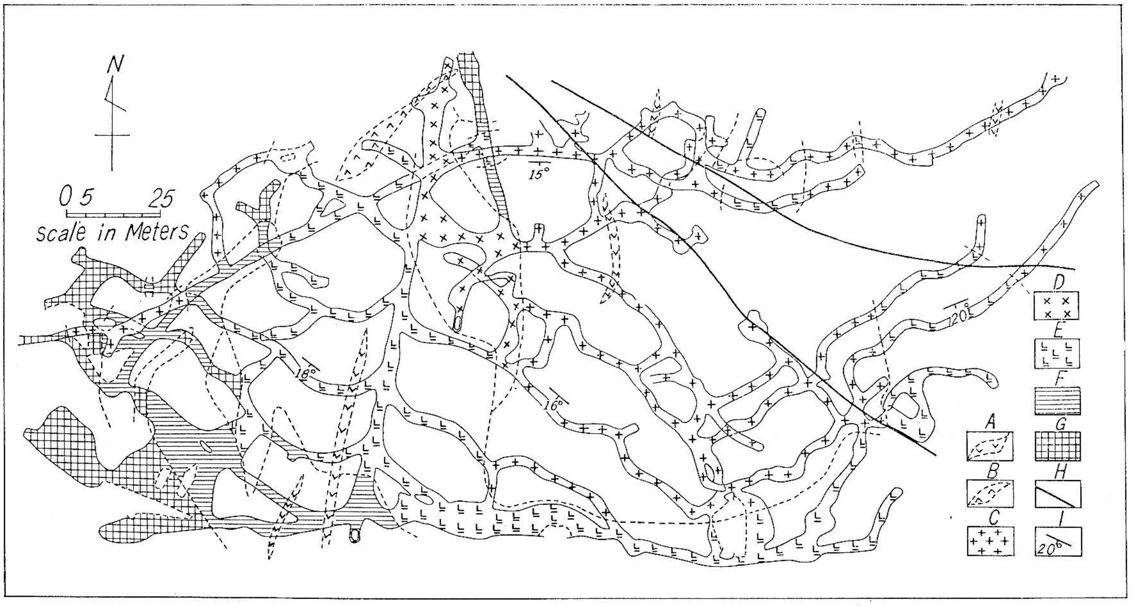


Fig. 7. Underground Geological Map of the Honko Deposits of the Higashiyama Mine. A : Andesite dike, B : Granite porphyry dike, C : Rengeji granite, D : Porphyritic granite, E : Aplite, F : Acidic hybrid, G : Kawai hybrid (basic hybrid), H : Fault, I : Strike and dip of the vein.

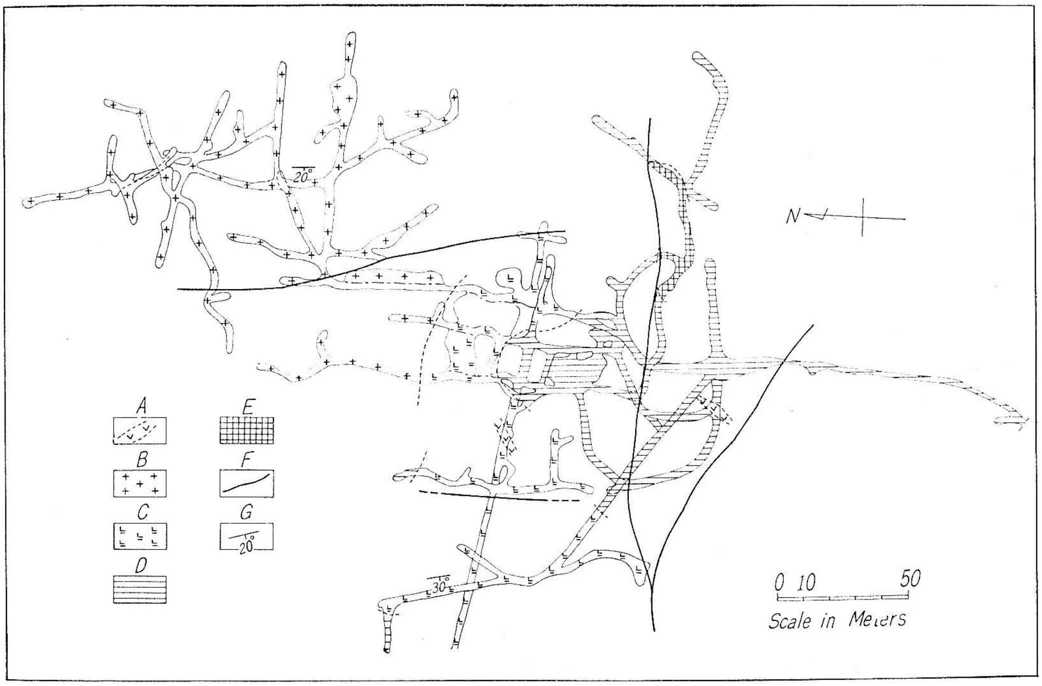


Fig. 8. Underground Geological Map of the Hinotani Deposits of the Daito Mine. A : Andesite dike, B : Rengeji granite, C : Aplite, D : Acidic hybrid, E : Kawai hybrid (basic hybrid), F : Fault, G : Strike and dip of the vein.

pied by the acidic hybrid. The aplite and porphyritic granite may be of marginal facies of the Rengeji granite, and furthermore, the acidic hybrid may have resulted from contamination between the aplite or porphyritic granite and the Kawai hybrid. In this acidic hybrid, numerous inclusions in rounded shape, dark-colored, are frequently observed. These inclusions resemble extremely quartz dioritic rock, and may be considered to have been derived from the Kawai hybrid.

The ore deposits are molybdenite quartz veins, which strike about N 50°W at their west end, N 70°E at their east end, and dip 15° to 20° S. They are from 10 to 50 cm in width.

Underground geological survey may reveal a marked tendency that the ore shoot of this deposit is commonly restricted to the central zone where both the aplite and the acidic hybrid are predominant, whereas in the marginal areas away from the central zone, the intensity of mineralization is suddenly weakened.

Generally speaking, the wall rock is intensely altered and is characterized by the presence of an orderly arrangement of several alteration zones such as zones of silicification, sericitization and chloritization, from the inner side of the veins outwards. In the peripheral zones where the intensity of mineralization is weak, however, the zones of both silicification and sericitization are often lacking, and the zone of chloritization alone comes into contact directly with the ore veins[12]. The schematic arrangement of each alteration zone along with its component minerals is shown in Fig. 9 and Table 3, respectively[13].

Molybdenite as an ore mineral is almost all fine-grained, and associated with quartz veins. They are found generally aggregated in several thin bands parallel to the vein. Where the vein is thick, however, coarse-grained

Table 3. Component Minerals of Each Alteration Zone

Fresh Zone	Chloritized Zone	Sericitized Zone	Silicified Zone
Quartz	Quartz	Quartz	Quartz and small amounts of Sericite
Plagioclase	Plagioclase Calcite Sericite	Sericite Quartz	
Orthoclase	Orthoclase Sericite	Sericite Quartz	
Biotite	Biotite Chlorite Pyrite	Sericite Pyrite	

flaky ones up to several centimeters in diameter are frequently found scattered around the boundary of vein quartz and other constituent minerals.

Where the wall-rock alteration is intense, the impregnation of molybdenite often prevails in the altered zones away from veins.

Pyrite is common accessory mineral, but galena, sphalerite, calcite and ankerite, etc. are also found in small quantities.

In addition, both the Sasadani andesite and the granite porphyry belonging to the Ouchidani granite occur as small dikes in the underground, which intrude along or cut across the ore vein (Fig. 10, 11).

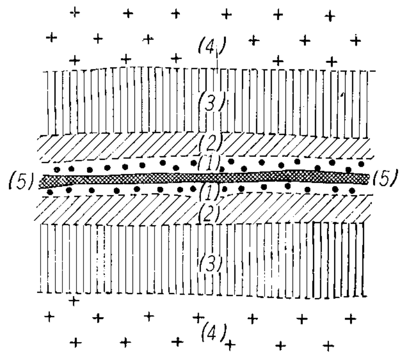


Fig. 9. Schematic Arrangement of the Alteration Zones.
1 : Silicified zone, 2 : Sericitized zone, 3 : Chloritized zone, 4 : Fresh zone, 5 : Ore vein.

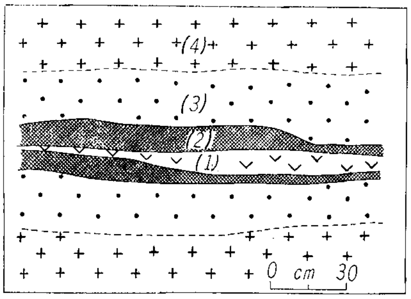


Fig. 10. Geological Relationships between Andesite Dike and Ore Vein (Sketch of side wall. Honko deposits, Higashiyama mine).
1 : Andesite, 2 : Molybdenite-quartz vein, 3 : Altered zone, 4 : Rengeji granite.
The andesite dike cuts the vein along.

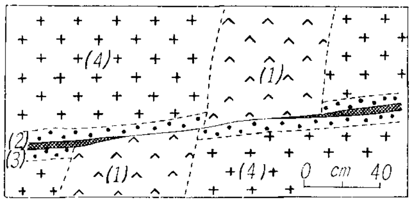


Fig. 11. Geological Relationships between Granite Porphyry and Ore Vein (Sketch of side wall. Honko deposits, Higashiyama mine).
1 : Granite porphyry dike, 2 : Molybdenite-quartz vein, 3 : Altered zone, 4 : Rengeji granite.
The granite porphyry dike cuts the vein. After its intrusion, the dike is dislocated along the vein.

(2) *Honko deposits of the Seikyu mine*—The deposits are located near the contact between the Rengeji granite and the Kawai hybrid, and include three veins such as the Yabuchiko, the Uwahiko and the Shin-Ichigoko veins. These ore veins all seem to have beed formed in nearly the same stage, filling fractures and joints in the country rocks, although they have different strike and dip. Geological aspects of these veins are as follows:

(i) Yabuchiko vein—The nature of this vein is extremely similar to veins of the Honko deposits of the Higashiyama mine (see the foregoing paragraph). That is to say, such geological features as kinds of country rocks, mode of occurrence of molybdenite, mineralogy of the constituent minerals, wall-rock alteration, etc. are almost all the same.

The vein strikes E—W near its west end, N 50°W near its east end, and dips from 15° to 20° S throughout the vein. It is commonly 5 to 30 cm in width, though, in places, thinned and in other places swelled.

As already described in the foregoing paragraph, there is also a tendency that ore shoots of this deposits are found restricted to the central zone occuppied by several kinds of rocks such as the Rengeji granite, the aplite and the acidic hybrid.

(ii) Uwahiko vein—This vein is found in the Rengeji granite area, and has a strike of N—S and a dip of 15°E, which averages about 20 cm in width with 100 cm in maximum.

(iii) Shin-Ichigoko vein— This vein occurs also in the Rengeji granite area, and strikes N 45°E, dips 10° to 15°S. In general, it seems to be inferior to the above-mentioned two veins both in width and in ore grade.

In addition, both the Sasadani andesite and the granite porphyry belonging to the Ouchidani granite occur as small dikes invading across and/or along the veins of this mine.

(3) *Hinotani deposits of the Daito mine*—The deposits also occur near the boundary areas between the Rengeji granite and the Kawai hybrid (so called basic hybrid), where the Rengeji granite is gradational into the aplite, and then this aplite also into acidic hybrid, from north to south end. Likewise in the case of the other deposits above-mentioned, there is found a predominance of the dark-colored, rounded inclusions in the acidic hybrid (Fig. 8).

This vein strikes generally N—S, dips 20° to 30°W and varies 10 to 100 cm in width. The general features of these deposits are nearly similar to those of the main deposits in this mining district. However, these deposits are somewhat different from the above-mentioned deposits both in the presence of considerable amounts of chlorite in the vein and in that molybdenite is generally coarse-grained and is associated with large amounts of pyrite.

In addition, the Sasadani andesite is found as small dikes, but rare.

(4) *Honko deposits of the Daito mine*—These deposits are located near the contact borders among the Rengeji granite, the Kawai hybrid and the Daito granodiorite. As a large part of these deposits had already been worked out, the present authors could not carry out a scrutinizing survey in

the underground. However, the underground data obtained near the south end of these deposits show that the general geological features are well in agreement with those of the Hinotani deposits of this mine. The vein strikes N 10°E, and dips 20°W, and varies 10 to 30 cm in width.

The Sasadani andesite occurs as small dikes, but very rare.

(5) *Minamiko deposits of the Seikyu mine*—These deposits occur within the Kawai hybrid area enclosed by the Ouchidani granite. The country rocks found in the underground are composed of both the acidic hybrid and the basic hybrid. The vein strikes generally N 45°E, dips 20°N, and varies 10 to 100 cm in width.

Molybdenite as an ore mineral is commonly fine-grained and found aggregated in thin bands parallel to the vein. Such a mode of occurrence is very similar to that of the other deposits closely associated with the Rengeji granite. Under the microscope, coarse-grained crystal aggregates of molybdenite and quartz have sometimes been crushed by the local post-mineral displacement of the vein. This texture is characteristic to the ores of this deposit. Pyrite is common accessory mineral, but sphalerite is also rarely found. In places, the sphalerite-pyrite-calcite vein, about 10 cm wide, is found cutting the molybdenite-quartz vein (Fig. 12). It may be the representatives of the latest stage of the molybdenum mineralization related to the Ouchidani granite.

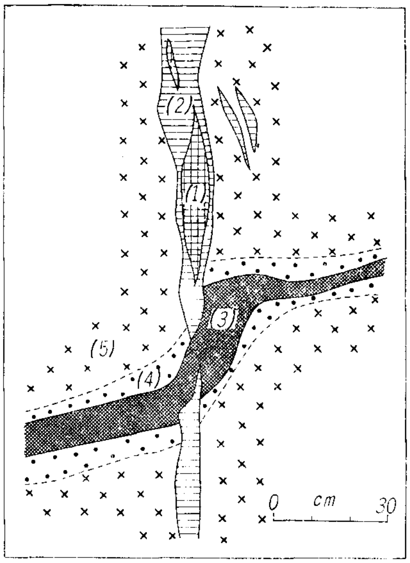


Fig. 12. Sphalerite—Pyrite—Calcite Vein cutting the Molybdenite-quartz Vein (Sketch of side wall. Minamiko deposits, Seikyu mine).
1 : Sphalerite, 2 : Calcite, 3 : Molybdenite-quartz vein, 4 : Altered zone, 5 : Kawai hybrid.

Wall-rock alteration in this deposit is not so intense as that of the main deposits occurring around the Rengnji granite, and only the chloritized zone is commonly recognized adjacent to the vein[14].

In addition, both the Sasadani andesite and the Seikyu quartz diorite occur occasionally as small dikes in the underground.

(6) *Other ore deposits*—As already stated, the Namera and the Kamitani deposits are not in operation at present, and the Saseko deposit is now

abandoned. The former two occur in the Rengeji granite, while the latter is in the Kawai hybrid.

Judging from the gangue and ore minerals which were mined before from each deposit, it is presumed that these deposits are all molybdenite-quartz veins. In these deposits except for the Saseko deposits which is not observable as the adit is burried, the Sasadani andesite is also found as small dikes.

(C) Some relationships between the kinds of country rocks and the ore shoots

(1) *Ore deposits associated with the Rengeji granite*—As already stated, the country rocks of the principal ore deposits associated with the Rengeji granite contain commonly several kinds of rocks; the Rengeji granite, the aplite (locally porphyritic granite), the acidic hybrid, and the Kawai hybrid (so-called basic hybrid). The aplite and the porphyritic granite are considered to be of the marginal facies of the Rengeji granite. The acidic hybrid may have been formed as the contamination products between the aplite and the Kawai hybrid before the molybdenum mineralization is commenced. The Kawai hybrid which is present as "roof-pendant" of the Rengeji granite within the map-area is presumed to have played the role of "cap-rock" controlling structurally the emplacement of the ore deposition. Accordingly, it is reasonably supposed that the position of ore deposition should be restricted near the contact zones between them, and moreover the ore shoots are usually found within the central areas occuppied by the aplite and the acidic hybrid.

(2) *Ore deposits associated with the Ouchidani granite*—As previously mentioned, both the Seikyu-Minamiko deposits and the Saseko deposits are found closely related to the Ouchidani granite. In this section, only the Seikyu-Minamiko deposits is concerned. The country rock of this deposit is commonly composed of the acidic hybrid together with the Kawai hybrid (so-called basic hybrid).

Likewise in the case of the principal deposits occurring within the Rengeji granite area, the Kawai hybrid is also believed to have played an important role as "cap-rock" during the process of the formation of this deposit. Although this deposit is inferior to those deposits associated with the Rengeji granite both in ore grade and in scale, the geological situations mentioned above lead to the suggestion that the more workable veins which may lie in depth near the contact zones between the Ouchidani granite and the Kawai hybrid may be probably found in the course of exploitation.

(D) Hypogene minerals and their paragenesis

The microscopic examination with a number of ore specimens taken from each deposit in this mining district shows that the ore consists mainly of molybdenite and quartz. Besides, biotite, plagioclase, adularia, epidote, pyrite, sphalerite, galena, calcite, and ankerite are also found as accessory minerals (Fig. 13, Table 4).

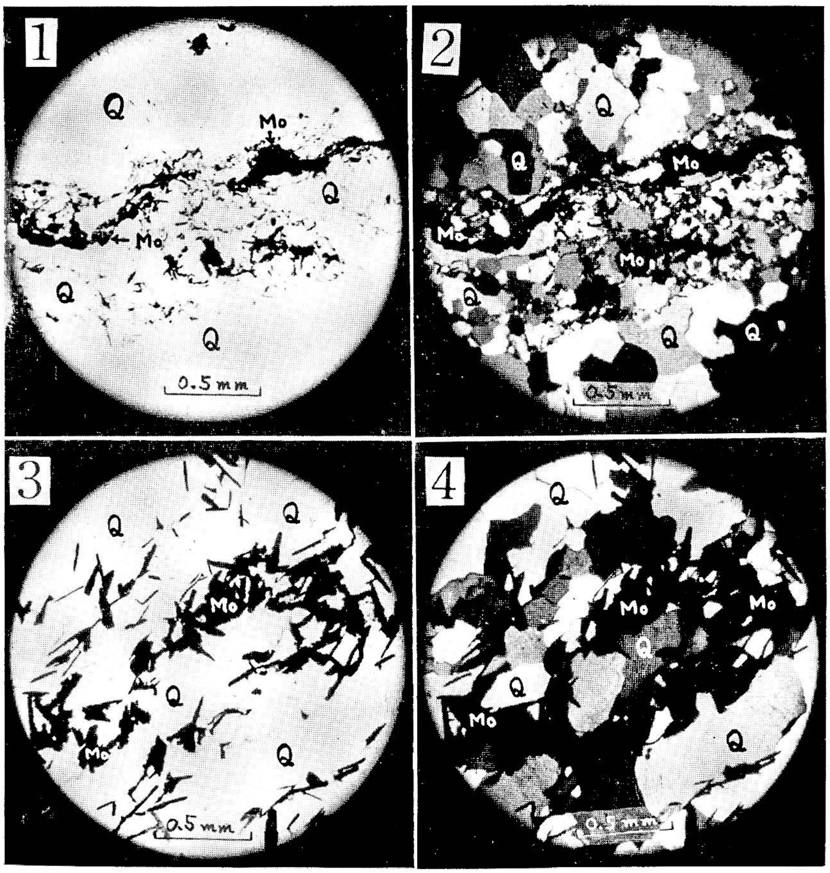


Fig. 13. Photomicrographs showing the Mode of Occurrence of Molybdenite.

Photo. 1 : Thin section of the ore specimen taken from the Honko deposits, Higashiyama mine (parallel nicols).
Molybdenite associated with fine-grained quartz formed in the later stage.

Photo. 2 : Same thin section (crossed nicols).

Photo. 3 : Thin section of the ore specimen taken from the Hinotani deposits, Daito mine (parallel nicols).
Molybdenite associated with coarse-grained quartz formed in the earlier stage.

Photo. 4 : Same thin section (crossed nicols).

Generally speaking, the coarse-grained molybdenite is usually in close association with the coarse-grained quartz, while the fine-grained one with the fine-grained quartz. The former is occasionally cut by the small veinlets of the latter (Fig. 13). The paragenetic sequence of the hypogene minerals determined in thin sections is shown in Table 4.

Table 4. Hypogene Minerals and their Paragenesis

	Earlier	Later
A	Biotite Plagioclase Adularia Quartz Molybdenite Pyrite	Biotite Epidote Quartz Molybdenite Pyrite Sphalerite Galena Ankerite Calcite
B	Quartz Molybdenite Pyrite Sphalerite	Pyrite Sphalerite Calcite

A : Molybdenum deposits associated with the Rengeji granite, B : Molybdenum deposits associated with the Ouchidani granite.

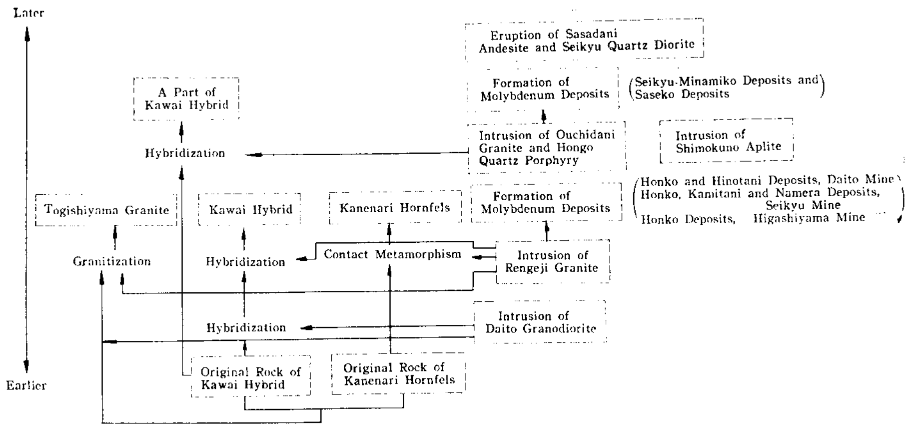
(V) Summary and Conclusions

Geological and mineralogical studies on the molybdenum deposits occurring in the Daito mining district lead us to the following summary and conclusions (Table 5).

(a) The original rocks of the Kawai hybrid and the Kanenari hornfels, which are presumably rocks of the Paleozoic formation, seem to belong to the oldest group of all the rocks occurring in the map-area.

(b) The Daito granodiorite is considered to be the oldest intrusive rock. Some part of both the Kawai hybrid and the Kanenari hornfels appear to have resulted from the metamorphism of their original rocks by this granodiorite magma.

Table 5. Gelogical Setting of Both the Molybdenum Deposits and the Rocks



(c) Following the intrusion of the Daito granodiorite, the Rengeji granite was intruded. It is probably in Paleogene epoch.

The Togishiyama granite, somewhat gneissose in texture, may have been formed from the process of granitization of certain pre-existing rocks by this granite magma.

The ore deposits such as the Honko deposits of the Higashiyama mine, the Namera, the Honko and the Kamitani deposits of the Seikyu mine, the Honko and Hinotani deposits of the Daito mine, which are all located in the marginal zone of the Rengeji granite body, is believed to have been formed by the post-igneous action of this granite magma. In these cases, the Kawai hybrid which occurs as "roof-pendant" within this granite area has played the role of "cap-rock" controlling structurally the emplacement of ore deposition.

(d) Subsequently, the Ouchidani granite have intruded soon after the intrusion of the Rengeji granite. This granite seems to have been consolidated at a comparatively shallow depth, and consequently has rather porphyritic texture.

Both the Seikyu-Minamiko and the Saseko deposits were formed closely related to this granite. Also in these deposits, the Kawai hybrid seems to have played an important role as "cap-rock".

(e) The Hongo quartz porphyry is considered to be of the chilled facies of the Ouchidani granite, and the Shimokuno aplite also to be closely related to the Ouchidani granite. They all may have intruded in succession in nearly the same age.

(f) The Sasadani andesite was erupted in Miocene epoch, and was followed by the intrusion of the Seikyu quartz diorite.

(g) The country rock of the principal ore deposits occurring around the Rengeji granite body consists mainly of several kinds of rocks such as the Rengeji granite, the aplite (locally porphyritic granite), the acidic hybrid and the Kawai hybrid (so-called basic hybrid).

The ore shoots of these deposits are usually found restricted to the central areas occuppied by both the aplite and the acidic hybrid.

(h) The wall rock adjacent to the vein is commonly characterized by the presence of an orderly arrangement of the silicified, the sericitized and the chloritized zones, from the inner side of vein to the outer. Where the intensity of the mineralization is remarkable, the wall-rock alteration is also intense.

(i) Both molybdenite and quartz are the principal constituent vein minerals. The microscopic examination in thin sections leads us to the recognition of the main two stages of mineralization. They are as follows:

(i) In the deposits associated with the Rengeji granite, minerals deposited in earlier stage are coarse-grained molybdenite and quartz, biotite, plagioclase, adularia, and pyrite. On the other hand, minerals deposited in later stage are fine-grained molybdenite and quartz, biotite, epidote, pyrite, sphalerite, galena, calcite, and ankerite. The former is occasionally cut by the small veinlets of the latter.

(ii) In the deposits associated with the Ouchidani granite, molybdenite, pyrite, quartz, and sphalerite were deposited during the earlier stage of mineralization, whereas pyrite, sphalerite, and calcite were deposited during the later stage.

References

1) K. Kinosaki ; On the Granite and the Tungsten-Molybdenum Deposits in the Chugoku Province. Geol. Report, Hiroshima Univ., Vol. 3, p. 61-77, 1952. (in Japanese)
2) T. Yamamoto ; Geology and Ore Deposits of the Daito Mining District, Shimane Prefecture. Geol. Report, Hiroshima Univ., Vol. 4, p. 1-14, 1954. (in Japanese)
3) Geological Survey of Japan ; Geology and Mineral Resources of Japan. 1st Ed., 1956 and 2nd Ed., 1960.
4) M. Sato and K. Takahashi ; Molybdenite Mineralization in the Green Tuff Formation, Waga-Gun, Iwate Prefecture. Min. Geol., Vol. 6, No. 20, p. 32-33, 1956. (in Japanese)
5) K. Tsuboya and S. Ishihara ; Tungsten and Molybdenum Ore Deposits and Uranum Mineral of the Komaki Mine, Shimane Prefecture. Min. Geol., Vol. 8, No. 32, p. 346-352, 1958. (in Japanese)
6) M. Sato and O. Kadota ; Uraniferous Molybdenum Deposits of the Takane Mine, Niigata Prefecture. Min. Geol., Vol. 11, No. 47, p. 456-459, 1961. (in Japanese)
7) M. Sano ; On the Molybdenum Deposits of the Daito District, Shimane Prefecture. Master Thesis, Faculty of Engineering, Kyoto Univ., 1963. (in Japanese)
8) T. Yamamoto ; Op. cit.
9) T. Yamamoto ; Op. cit.
10) T. Takimoto ; Studies on the Tin Deposits of Japan. Jap. Jour. Geol. Geogr., Vol. 19, p. 195-241, 1944.
11) J. Suzuki and T. Nemoto ; On the Chemical Composition of the Granitic Rocks of Japan. Jour. Jap. Assoc. Min. Petr. Econ. Geol., Vol. 8, p. 51-61, 1936. (in Japanese)
12) G. M. Schwartz ; Hydrothermal Alteration as a Guide to Ore. Econ. Geol., Fiftieth Anniv. Vol., Part 1, p. 300-323, 1955.
13) G. M. Schwartz ; Alteration of Biotite under Mesothermal Conditions. Econ. Geol., Vol. 53, p. 164-177, 1958.
14) G. M. Schwartz ; Op. cit.