Geological Notes on the Yamato Mine, Yamaguchi Prefecture*

By

Hiroshi MIYAKE and Kyûbê AKATSUKA

With 3 Tables, 3 Text-figures, and 2 Plates

ABSTRACT: Geology distributing in the surroundings of the Ofuku mining district has been outlined. Noteworthy is that so-called pyrometasomatic effects of certain intrusives on limestone intercalated in the sedimentaries appeared specifically in the vicinity of the Yamato mine have not been discernible to such extent as was formerly emphasized by some authors but some other views concerning the ore genesis have surely been obtained.

CONTENTS

I. INTRODUCTION

The Yamato mine which was till 1940 named the Ofuku mine is situated in Ofuku-chô, Miné City, Yamaguchi Prefecture, about 1.5 Km southwest of the Ofuku station on the Miné railway line. They say that the mine was already worked on a small scale from the end of the Tokugawa Period to the end of the Meiji Period and in 1915 numbered as one of the principal mines in Japan for production of copper ores which were refined on the spot through the "Mabuki" process since the end of World War I. Recently the ores bearing copper, lead, tungsten and other sulfides have been dressed by means of tables and through flotation method while considerable amounts of wollastonite have been excavated till the close of mining in January, 1962. In the environs of the mine are distributed several small-scaled mines named Sanjô, Nagao, Fukurei, Fukushige and some others distinguished from one another in mineral assemblages as well as in their proportions, almost all of which have already been closed.

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On the basis of the view given by Kawai who has, according to the authors' suggestion, re-investigated the geology distributed in the region concerned and made the results obtained public at the general meeting of Geol. Soc. Japan in 1962. The contents referred to hereunder have been somewhat revised.

Geologically, the district concerned is consisted mainly of a part of the paleozoic formations together with a diorite stock intruding the former, in which some ore deposits grouped into those derived through so-called contact or pyrometasomatic effects are found scattered within the area.

Geology and the ore deposits included in the district have so far been referred to by some authors such as KATÔ (1913, 1917 and 1937), OGURA (1921), SUZUKI (1932), UENO and DOI (1956), SEKINE (1958). KATÔ (1937) classified the deposits in question ordinarily into a type of contact deposits, while SUZUKI reported the detail of the deposits with special reference to the minerals produced, while the researches were carried out by UENO and DOI concerning the field geology and by SEKINE with regard to wollastonite. The works published by TORIYAMA (1954, 1957), MURATA (1961) and KAWAI (1962) are stratigraphically important, although there may be room for inspection specifically in relation to genesis of ore formation, to which the present writers want to pay attention in this report.

II. OUTLINE OF GEOLOGY

The region under consideration is located in the part west of the Ofuku plateau as well as in the westernmost part of the plateau. Along the western margin of the plateau the narrow zone of alluvial plain accompanied with the Asa River running through its central part is found developed from north to south, intervening between the eastern plateau and the western mountainous area. It is to be noted that the topography appeared in this district might have been controlled by the geologic structures to certain extent.

The western margin of the Ofuku plateau composed of the Akiyoshi facies (limestone) lying over the Yamaguchi facies (non-calcareous) at the bottom is about 300 m high above the sea-level, soaring as a steep cliff (*ca.* 70° in angle) toward

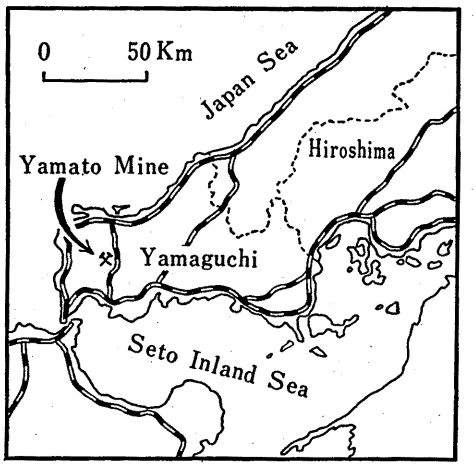

FIG. 1. Index map of the Yamato mine.

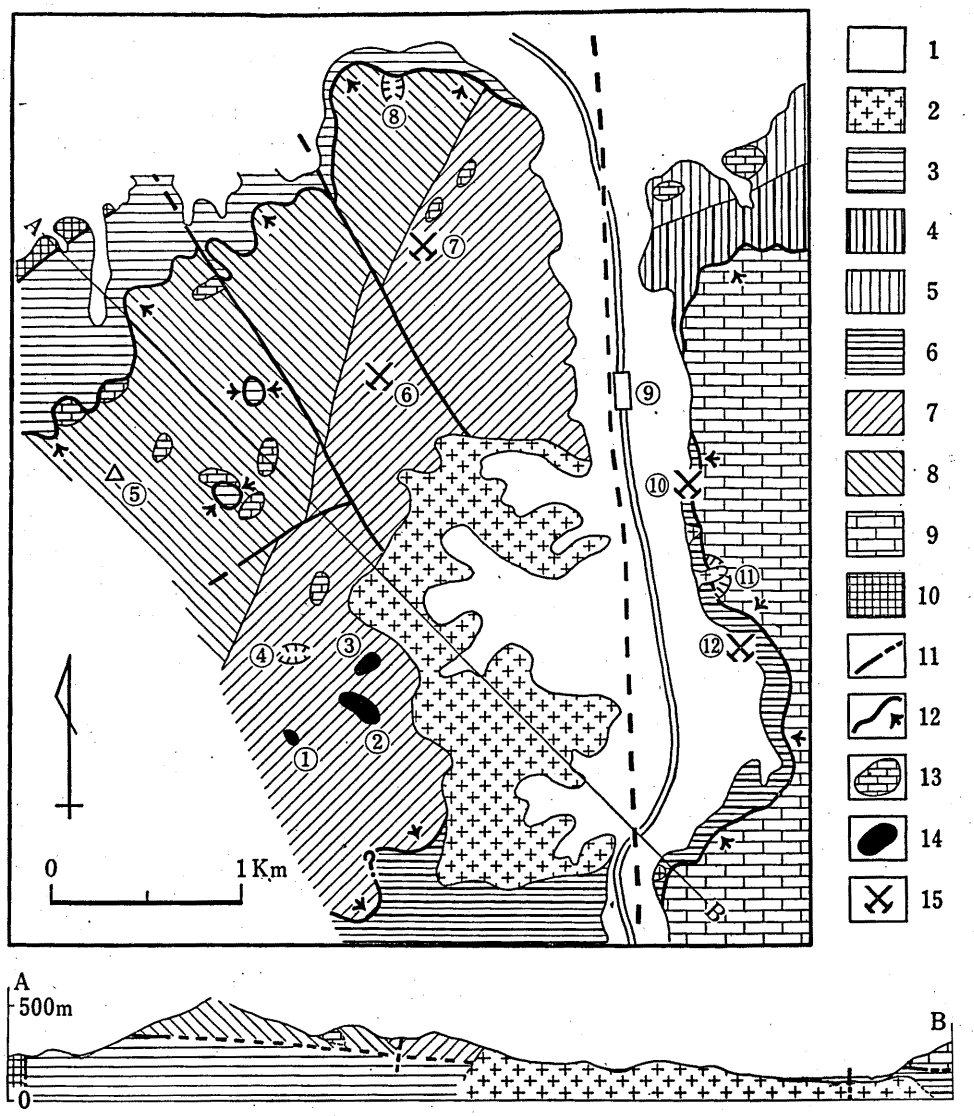

FIG. 2. Geological map of the Yamato mining district.

1. Alluvium 2. Quartz diorite 3. Miné G. 4. Serita F. 5. Ryūgenji F. 6. Tsunemori G. 7. Nishihata F. 8. Kuwabara F. 9. Akiyoshi Limestone 10. Dai F. 11. Fault 12. Thrust 13. Limestone lens 14. Ore deposit 15. Mine

① Dôtoko deposit ② Daido deposit ③ Fukuju deposit ④ Kanegahara mine ⑤ Mt. Gampi ⑥ Sanjô mine ⑦ Nagao mine ⑧ Ofuku mine ⑨ Ofuku station ⑩ Fukurei mine ⑪ Quarry of Tôa Sangyô Co. ⑫ Fukushige mine

the plain.

In the western and northwestern areas are arranged some ridges with a northeastward trend, of which Mt. Gampi, the principal summit in the district, is 580

m high above the sea-level, and the main parts of which are composed chiefly of cherty rocks of the Yamaguchi facies. In the western part of the mountainous area is found distributed the coal-bearing Miné group, a member of the Mesozoic formation, composing the hilly lands, while the Dai formation composed of phyllitic rocks is exposed in a small scale in the northwestern corner of the district. In the hilly area located in the southeastern part of the ridges and at the base in the southern half of the alluvial plain is found intruded the quartz-diorite.

A. PALEOZOIC FORMATION

Stratigraphy of the formation has so far been established by TORIYAMA (1957) and MURATA (1961), as is picked up in Table I especially concerning the Ofuku district. These results are not in coincidence with each other, whereas the result obtained by the former is areally and lithologically not so much different from the data of the present authors.

1. Akiyoshi Facies (Akiyoshi Limestone Group)

This member representing one of the main sedimentaries constructing the Ofuku plateau located in the eastern part of the district is composed merely of saccharoidal limestone subjected probably to the thermal effect of quartz diorite, resulting in recrystallization of calcite, the grain-size of which is invariable within width of 100 m from their contact but becomes finer with distance. At the quarry of Tôa Sangyô Co. situated between Fukurei and Fukushige mines, the contact of limestone with quartz diorite occurring as an apophysis with width of about 20 m bears an appearance of discolored or altered vein, with width of 2 cm on an average, which is composed of pinkish, earthy matters including a small amount of garnet recognized merely through x-ray diffraction but no traces of any other skarns. On both sides along the vein, any sorts of minerals proved as reaction products are nowhere found contained.

Although the main ore bodies of the Fukurei mine are, according to the description of SUZUKI, considered to have deposited in crystalline limestone and, because of being closed, are now not confirmed, it seems more probable on the basis of present occurrence of the remainder that the ores might have been produced in the Tsunemori formation lying under the limestone and along the fault plane of the Akiyoshi thrust demarcating both formations.

2. Yamaguchi Facies (Non-calcareous Groups)

The member is topographically into two parts: One constructs the mountainous area located in the western part of the district and the other the basal parts lying under the Akiyoshi facies.

The former is composed mainly of chert associated with fine-grained sandstone and silicious slate as well as small lenses or irregular masses of limestone while chert and others are slightly metamorphosed into hornfels and limestone into sac-

TABLE 1. STRATIGRAPHY AND CORRELATION OF PALEOZOIC GROUPS APPEARED IN OFUKU DISTRICT

	Akiyoshi Limestone Group		Noncalcareous Groups									
			TORIYAMA (1957)						MURATA (1961)			
	TORIYAMA (1957)	MURATA (1961)										
Permian	Puα	P IV			Beppu Group	Sambonmatsu F.	Tsunemori Group	Shiraiwa F.	Ofuku Group	Tsutsumi F.	Beppu Group	Kawabara F.
	Rmδ	P III				Serita F.		Tsunemori F.				Ryūgenji F.
	Pmγ											
	Pmβ					Ryūgenji F.		Aigyô F.				
	Pmα	P II								Maki F.		
	Plγ		Gampi Group	Nishihata F.		Katada F.						Katada F.
	Plβ	P I		Kuwabara F.								
	Plα			?								
	?	?								?		
Carboniferous	Cmβ	C IV								Aigyô F.		
	Cmα	C III										
	Cl	C II										
		C I										

charoidal one through the thermal effect of quartz diorite near their contacts.

In the eastern region, the same formation lying under the Akiyoshi facies is composed mainly of fine-grained sandstone in the southern area, and of chert and slate intercalating lenticular limestone in the northern area.

The Yamaguchi facies in this district has already been strato-paleontologically classified by TORIYAMA, as is shown in Table 2.

TABLE 2 STRATIGRAPHY OF NONCALCAREOUS PALEOZOIC GROUPS APPEARED IN OFUKU DISTRICT
(abstracted from the data given by TORIYAMA, 1957)

Western Mountainous Area				Eastern Area (Lower Part of the Ofuku Plateau)		
Southernmost Part		Central Part		Southern Part	Northern Part	
Tsunemori G.	Shiraiwa F. Tsunemori F. Aigyô F.			Tsunemori G.	Beppu G.	Serita F. Ryūgenji F.
		Gampi G.	Nishihata F. Kuwabara F.			

On the other hand, stratigraphy of the same formation has also been established by MURATA, as is indicated in Table 3.

TABLE 3 STRATIGRAPHY OF NONCALCAREOUS PALEOZOIC GROUPS APPEARED IN OFUKU DISTRICT
(abstracted from the data given by MURATA, 1961)

Western Mountainous Area				Eastern Area (Lower Part of the Ofuku Plateau)	
				Southern Part	Northern Part
Ofuku G.	Tsutsumi F. Maki F. Aigyô F.	*fault*	Beppu G. Ryūgenji F. Katada F.	Aigyô F.	Tsutsumi F. *fault* Katada F.

As far as the lithologic features appeared in the district are concerned, the data given by TORIYAMA are, if not perfectly, in good accordance with the results ob-

tained by the present authors.

Gampi Group: The group has once been named the "Gampi series" by KOBAYASHI (1940) and later confined to that distributed merely in the western mountainous area in the surroundings of Mt. Gampi by TORIYAMA (1954). According to his view, the group is furthermore lithologically dividable into two parts such as the Kuwabara (lower) and the Nishihata (upper) formations. The Kuwabara formation is situated in the western half of the western mountainous area, pointing to NNE-SSW in distribution. Its lower part occupying about two third of the total is composed of chert and the upper remainder, of black-colored slate associated with thin lenses of chert. The chert contained in the lower part is massive, not stratified and milky grey, milky white, milky blue or green in color, while the clayslate comprised in the upper part is considerably hard in property, mostly black but variable into bluish black in color, silicified in parts and intercalates thin lenses of chert and fossiliferous limestone. The Nishihata formation is developed in the eastern half of the same mountainous area with distributional tendency similar to that of the Kuwabara formation, apparently conformable with the latter, and composed chiefly of chert associated with sandstone, slate and minor lenses of limestone. The chert included in this formation is massive, milky white, milky green or greenish blue in color, and hardly distinguishable from that belonging to the lower formation. The sandstone is hard in property, fine-grained and dark bluish in color. The slate is also hard, bluish black in color and hardly discernible from chert in the silicious parts. The lenticular limestone is crystalline and saccharoidal, accompanying no traces of fossils but skarn minerals in parts.

Basing on the report given by MURATA, the Gampi group is dividable into the Ofuku and Beppu groups. Judging from geological map, the Kuwabara formation is considered to be distributed within the area including the Katada and Ryūgenji formations of Beppu group. According to his view, most parts of the Nishihata formation are involved roughly in the Tsutsumi formation of the Ofuku group and a part distributed in the southeastern area is in the Maki formation of the same group.

TORIYAMA was of opinion that the Kuwabara formation is covered conformably with the Nishihata formation, whereas MURATA pointed out that the Katada and Ryūgenji formations come into contact with the Tsutsumi formation with a fault, and the Miné group is probably included in the area demarcated with faults paral to the strike of the Ryūgenji formation within the latter. As for this regard, small-scaled exposures of conglomerate and sandstone assumed to belong to the Miné group are confirmable in the northward valleys north of Nishihata and considered as a sort of 'Fenster' opened in the Kuwabara formation thrusting up on the very group. Whereas the Tsutsumi formation has been described by MURATA to be rich in slate with no chert, the facts are that the formation in this area to be grouped into the same member is rather predominant in chert together with fine-

grained sandstone specifically within the compound of the Yamato mine situated in this Tsutsumi formation, and there are many outcrops of chert, a part of which is being excavated as so-called "soft chert" in the Kanegahara mine. In consequence, it seems unreasonable that the formation located in the area including these mines has been taken as the Tsutsumi formation. Moreover, as was referred to by MURATA, the area concerned is located on the northern wing of anticlinal part of the Tsutsumi formation bearing the dip of 60°–80° SE and subjected to severe fracturing. Accordingly, it seems not reasonable that the formation appeared in this area is regarded structurally as a northeastern extension of the Tsutsumi formation and, as will later be alluded to, there is a room for further scrutiny concerning the structure in question.

The ore deposits of the Yamato and Sanjô mines are found formed in, or near, the contact between chert and lenticular limestone belonging to the Nishihata formation and the chert is now being excavated at the Kanegahara mine.

According to TORIYAMA, the Gampi group is demarcated with the Tsunemori group developed in the southernmost part of the western mountainous area with a fault revealing EW trend and thrusts up on the Miné group, a member of the Triassic formations distributed in the northwestern region, with the Gampi thrust denominated by TORIYAMA, representing seemingly a monoclinal structure with strike of N 10°–30° E and dip of 50°–80° SE. Because of bad exposure and of complicated structure, it is very difficult to discern the relation between the Gampi and Tsunemori groups. It however seems that, as was pointed out by KAWAI, the former lies on the latter in the relation of thrust.

On the other hand, both northern and western parts of the Gampi group come into contact with the Miné group with thrust. Trend of this thrust is used to revealing local variations showing, for example, N 50°–60° W in strike and 60° SW in dip at the bottom of the Ofuku mine south of Mankô, nearly NS in strike with high angle of eastward dip in the area west of the mine, and EW in strike in the area furthermore west of the above-mentioned. Moreover, chert of the Gampi group is recognizable thrusting up on the Miné group in the area north and west of Mankô. Taking into account of local variations in trend and of 'Fenster' alluded to already, the plane of the Gampi thrust is considered rich in irregular relief while the crustal movements might have taken place after the thrust concerned.

The Gampi group bears a trend of EW–N70° W with dip of 40°–60° S at the Ofuku mine wherein so-called 'soft chert' is included in the related group, whereas the chert composing most of the Nishihata formation is massive, rich in joints but lacking in stratification. In view of these facts as well as seemingly irregular occurrence of limestone observed in the gallery of Yamato mine, the structures of the Gampi group are believed not so much simple as was reported by TORIYAMA but strikingly complicated and therefore necessiates more detailed inspection in relation to the ore genesis.

The formation appeared in the eastern locality situating from the central to the

southern part of the mountainous area is altered into hornfels through intrusion of quartz diorite, and limestone included in the Nishihata formation also reveals saccharoidal feature through the same effect.

Although it is difficult to determine the stage of formation merely with the data obtained in this research the Gampi Group is chronologically combined with the middle Pennsylvanian by TORIYAMA.

Tsunemori Group: The group was once named the "Tsunemori series" of the Paleozoic formation by KATAYAMA (1939) and investigated subsequently by KOBAYASHI and then in detail by TORIYAMA, according to whom it was divided into three parts such as the Aigyô (lower), Tsunemori (middle), and Shiraiwa (upper) formations. As has been referred to already, the Tsunemori group is distributed in contact with the Gampi group with a thrust in the area locating from the southernmost part of the western mountainous land to south and under the southern part of the Akiyoshi limestone coming into contact through the Akiyoshi thrust in the eastern area. In the southernmost part of the mountainous area, all of the group are found in good continuity from the lower to the upper member, while the lower one is apt to appear in more predominance with approaching to east and the upper one, with approaching to west. Whereas the fact is that the group indicates a sort of monoclinal structure with strike of NE-SW and dip toward NW within the district, it may represent the northwestern wing of antincline. Each formation of this group is nominally in correspondence respectively to the Aigyô, Maki and Tsutsumi formations of the Ofuku group but each horizon is not so. The group in question is composed mainly of slate, sandstone and their alternations accompanied with no traces of chert or silicious rocks in the western area, while that lying from the southern to the central base of the Ofuku plateau is consisted mainly of brown-colored, massive, and fine-grained sandstone without silicious or calcareous rocks. The member grouped by TORIYAMA into the Tsunemori formation in this area of the base of the Ofuku plateau seems to be corresponding to the Aigyô formation named by MURATA, although both are stratigraphically incongruous with each other. The ore deposits of the Fukushige mine and a part of those of the Fukurei mine are found produced in this formation while a sort of skarn vein composed mainly of hedenbergite is intervened in fine-grained sandstone of the very formation in a locality situating between two mines mentioned above.

The Tsunemori group is found altered through thermal effect of quartz diorite into hornfels in lower grade widely in the surroundings of their contact.

According to TORIYAMA's view, sedimentation of this group is considered to have been continuous during certain period from middle to upper Permian while MURATA is of opinion that, of the Ofuku group, the Aigyô formation is concerned with the middle Carboniferous, the Maki formation with the lower Permian, and the Tsutsumi formation with the upper Permian, the former two being related unconformably to each other.

Beppu Group: The part constructing the northern base of the Ofuku plateau was assumed the northeastern extension of the Gampi series by KOBAYASHI. This group was distinguished by TORIYAMA from the Gampi group because of difference in stage, structures and geologic unit whereas both groups are hardly discernible one from the other in lithologic feature. Basing on his opinion, the group is divided into four formations named the Katada, Ryūgenji, Serita and Sambonmatsu formations respectively in ascending order of sedimentation. Within the district under consideration, the upper part of the Ryūgenji formation as well as the Serita formation are distributed while it seems that the Katada formation (Beppu group) named by MURATA is corresponding to the former and his Tsutsumi formation (Ofuku group) to the latter, both being, in opposition to TORIYAMA's view, considered to be continuously developed from the western mountainous area to northeast.

The Ryūgenji formation by TORIYAMA in this area distributed narrowly with EW trend in the northernmost base of the Ofuku plateau is massive, almost not stratified and composed of milky bluish green-, green- or milky white-colored chert associated with lenses of limestone. The Serita formation developed conformably on the southern side of the Ryūgenji formation with a trend similar to the latter is consisted of black- to brownish black-colored clayslate intercalating sandstone but no chert. These two formations are, after MURATA, believed to come into contact with each other with a fault but the fact is of obscurity. The Akiyoshi limestone is found thrusting up on the southern side of the Serita formation.

It seems general that the Beppu group distributed in this district discloses a trend of ENE–WSW with southward dip.

Dai Formation: A part of the formation named by TORIYAMA are surrounded and demarcated by the Miné group with fault in the northwestern corner of the district, being composed of phyllitic slate and belonging to a member of so-called Sangun metamorphics.

B MESOZOIC FORMATION

Miné Group: The group belonging to the upper Triassic in age is found developed widely on the northwestern hilly land within the district and composed of alternation of sandstone and clayslate intercalated with conglomerate and coal seams, displaying a general strike of N 10° E with dip of 30°–50° W. As was already mentioned, the Kuwabara formation of the Gampi group is observed thrusting up on this group from the southeastern side. Within the region under consideration the Miné group is locally predominant in conglomerate displaying variation in diagenetic grade. For example, the conglomerate is compactly consolidated in the area south of Mankô and happens to occur as very loosened state along the road from Mankô to Kami-tashiro. The group concerned is apt to reveal the foldings with variations of strike and dip in small period. These minor foldings

are not considered to have been derived directly from the effect of thrust, since any deformations ascribed to fracturing or others are not recognized along the thrust plane. Moreover, a remarkable fact is that conglomerate and sandstone of the Miné group is cropped out as a sort of 'Fenster' in the Kuwabara formation at two localities situating about 1 Km north of Nishihata.

C Dioritic Rocks.

The main intrusive exposed in the district is represented by dioritic rock locating from the hilly land in the southern half of the central area to the base lying under the eastern alluvial plain, revealing as a semi-elliptical stock or boss with a scale of about 2 Km (NS) × 1 Km (EW), and the apophyses relating probably to the main intrusive are surely recognized appeared near the entrance of the Fukuju and Hôrai gallery of the Yamato mine on its western side as well as at the quarry situating between the Fukurei and Fukushige and so on.

The dioritic rock is found intruding the Nishihata formation on the western and northern sides, the Tsunemori group on the southern side, and the very group and the Akiyoshi limestone on the eastern side, while it is especially to be noted that its apophyse are evidently observed penetrating the limestone thrusting up on the Tsunemori group through the thrust plane. Their thermal effects on the surrounding sedimentaries are not of high grade but appeared widely, resulting merely in alteration into biotite-hornblende hornfels or into crystalline limestone. In relation to this regard, formation of the skarn minerals will be referred to later.

The intrusive seems to indicate a tendency liable to be subjected to weathering, to form the weathered zone thickly, to be eroded, and to reveal a distinct distribution topographically. The main parts of this intrusive are more acidic in lithologic property than the margins of its own and of dark grayish-colored granodioritic facies containing an abundance of biotite together with brownish green-colored hornblende as femics, andesine, quartz and orthoclase as felsics, and apatite, zircon, magnetite and titanite as accessories. On the other hand, the margins of the similar parts are used to showing a gradual variation within width of about 20 m into more basic, dark-colored facies of finer-grained quartz-biotite-hornblende diorite comprising more abundance of hornblende than in the acidic parts and plagioclase together with a scarce amount of quartz and orthoclase as well as accessories similar in kind to those in the main part.

In general, the apophysis-like parts are grayish in color, medium-grained, lacking in marginal facies, less predominant in the total amount of colored minerals other than hornblende indicating relatively more quantity than that of others, and more acidic in property than in the main part of dioritic intrusive. These parts show such a local variation as is observed in the facies, containing biotite and diopside? in similar amount and quartz in a slight excess compared with those in the main mass, found at a locality between the Fukurei and Fukushige mines,

or as is recognized in that, containing merely pyroxene in less amount together with plagioclases, orthoclase and quartz respectively in equal quantity, appeared at the entrances of the Fukuju and Hôrai galleries. Of two, the former is found here and there cut by the veinlets of aplite composed of quartz and orthoclase accompanying plagioclase and an extremely small amount of biotite flakes.

Activity of the dioritic intrusive is yet remained to be chronologically determined because of no evidences other than its intrusion into the Paleozoic formations within the district concerned but it is for the present reasonably considered to have been taken place at certain stage of the last Mesozoic in age.

D PORPHYRITE DIKE

The dike, about 3 m in width and blackish grey in color, with strike of N 45° W and southward dip in high angle, is occurred on the southern side of the Sanjô mine, comprising megascopically recognizable phenocrysts of plagioclase as well as microscopically discernible quartz and hornblende enclosed in the groundmass of feldspar, quartz and extremely little amount of biotite flakes which are considered to have been subjected to deuteric effects to certain extent. It is naturally assumed to have injected at certain stage subsequent to the activity of dioritic rocks. The dike resembling this porphyrite dike was described by SUZUKI in the gallery of the Fukurei mine whereas it is found exposed nowhere in field.

E GEOLOGIC STRUCTURES.

Within the district are appeared two remarkable thrusts, of which one, named the Akiyoshi thrust, made the Akiyoshi limestone thrust up on the noncalcareous group and the other named the Gampi thrust did the Gampi group so on the Miné and Tsunemori groups. In spite of the previous view that the former might have been related to the Akiyoshi orogeny and the latter to the Ôga orogeny, both are for the present believed by YABE (1958) and KAWAI to have been simultaneous in age. As is deducible from inspection of geologic distribution, these thrusts manifest local irregularity in relief but are roughly observed as if they moved on the similar level of the same plane, suggesting that both are nothing other than the only one. As far as the region is concerned, these thrusts might have been active at a stage subsequent to sedimentation of the Miné group and prior to intrusion of dioritic rocks since the thrust plane is observed injected by an apophysis of the latter, and is, as was stated by KAWAI, considered to have been constructed through the Ôga orogeny at certain stage after sedimentation of the Kenseki group and before the intrusion of porphyrite. On the other hand, there are two systems of faults running through, and controlling structurally, the noncalcareous group of the Paleozoic formation: One revealing a trend of NNW-SSE is observed cutting across the Gampi thrust and represents the strike of pophyritic dike while the other indicates a trend of ENE-WSW. It seems that these faults were not extend-

ed into the dioritic mass, though the reality be not confirmable because of no outcrops observed in field. In view of the relation alluded to above, these systems are reasonably believed to have been formed at a certain stage subsequent to the thrust and prior to the intrusion of dioritic rocks.

Another noticeable system denominated the Ofuku-Yoshinori tectonic line (topographically conspicuous but essentially not so much large-scaled) by TORIYAMA is evidently observed dividing the district topographically into the eastern and western areas roughly along the Asa River, and its formation seems to have been later in stage than the activity of dioritic rocks.

Other minor faults having no relations to control of the geologic structure on a large scale are discovered everywhere within the district. Some of them are found cutting the ore bodies in question either with an EW trend or with a NS trend, accompanying a remarkable amount of fault clays.

III. NOTES ON ORE DEPOSIT

As has been stated, the ore deposits worked in several mines situating around the dioritic mass have hitherto been considered commonly as those derived from contact effects of the diorite concerned. It however seems general that all these deposits in this district are found nowhere at the contact of the intrusive with the surrounding sedimentaries or in the intrusive itself but rather observed merely in the sedimentaries distant from the very intrusive.

In case of the Yamato mine, igneous rocks other than a granodioritic apophysis injecting into chert with ordinary thermal effect near the entrance of the Fukuju and Hôrai galleries are not observable in the neighborhood of the ore deposits as far as the inspection is concerned only under the land-surface, but the dioritic mass is situated 100 m in minimum and 800 m in maximum far from the deposits, as is recognizable on the land-surface. In the Fukurei mine, occurrence of the ores along the porphyrite dike injecting into the Akiyoshi facies was described by SUZUKI but is now not confirmable because of close of the mine. All the deposits other than those occurring in the very mine are found comprised always in the Yamaguchi facies, a member of the noncalcareous group, associating a small amount of lenticular limestones, which are also actually observed in the gallery, and any deposits are nowhere found in the Akiyoshi limestone facies. In the light of these facts it is essentially difficult to combine the genesis of ores limitedly with contact effects of diorite intrusion on the limestone. It is furthermore the fact that the deposits appeared in the district are respectively characterized in mode of occurrence, mineralic constituents and their assemblage, and proportion of their contents. The detail will later be disputed with reference to genesis of the ores.

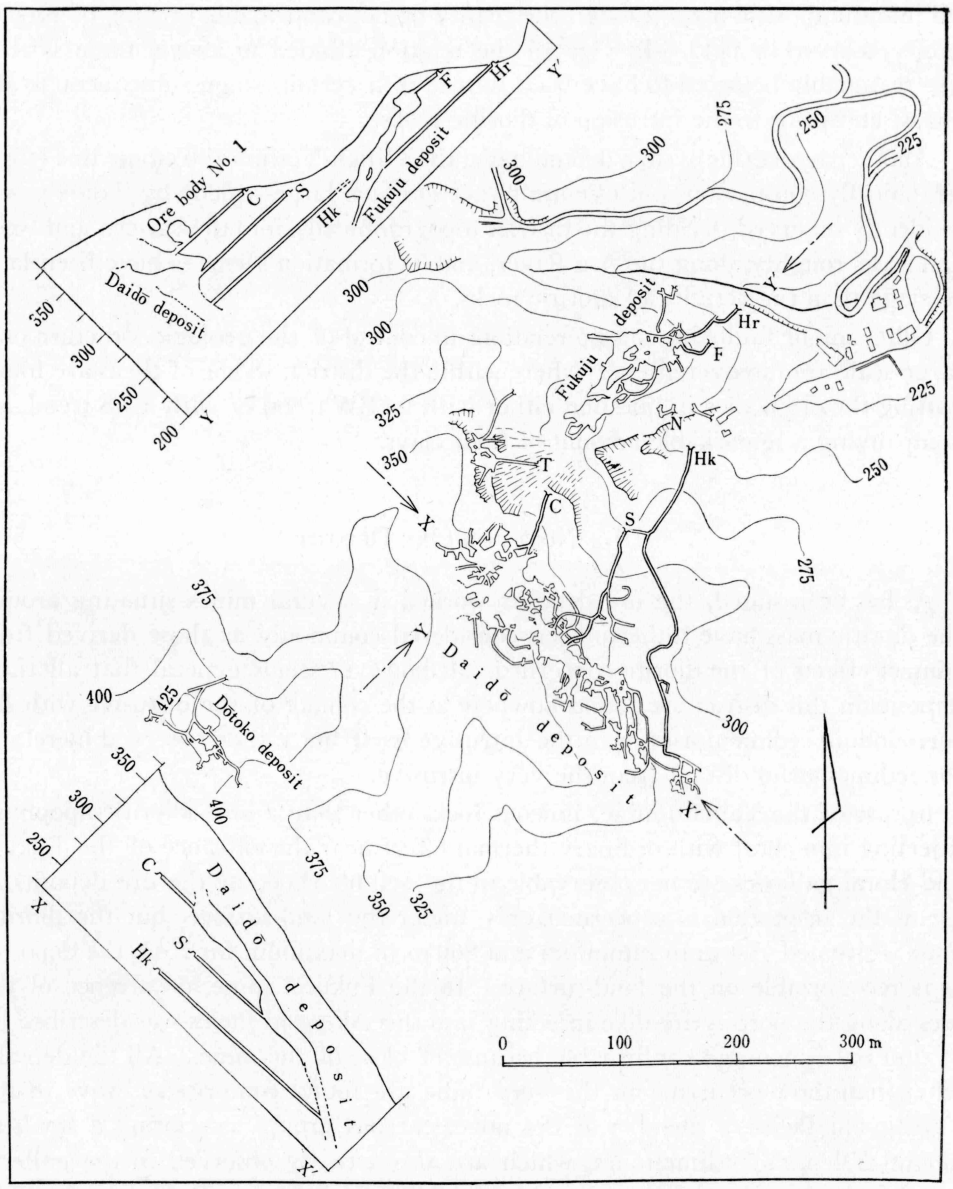

Fig. 3. Projection of the deposits and galleries in the Yamato mine.

C. Chūgiri-kô F. Fukuju-kô Hk. Hôkoku-kô Hr. Hôrai-kô
N. Namari-kô S. Shinsei-kô T. Tsûten-kô

Description of the Yamato Mine

The Yamato mine is the only one that has been worked in the district. The deposits concerned are, as has been alluded to already, found contained chiefly in

chert and also in limestone or in its contact with chert in a part of the Nishihata formation composed mainly of chert associating fine-grained sandstone and small-scaled limestone of irregular shape.

The chert is grayish white or white in color, massive in property, and nearly not stratified. The sandstone is fine in grain-size, extremely silicious, massive in property, and almost without stratification. The masses of limestone are used to appearing with various trends and scales, and occurrence of platy, massive, and lenticular shapes in discordance with stratifications of country rocks. Although MURATA was of opinion that the formations in this district were subjected to severe fracturing, the fact is that such a phenomenon as was pointed out is not ascertainable at least within the galleries of the mine, and the formations concerned are massive on the whole but altered to a certain extent through thermal effects. To clarify the geologic structures is of due significance in order to determine the distribution and structures of the ore bodies under consideration but the details other than suggestive existence of the thrust locating between the Paleozoic and Triassic formations on the northern side of the mine and other thrust in this mine are still now remained to be pursued for inspection.

In the Yamato mine are there three principal deposits called Dôtoko, Daidô, and Fukuju from south to north together with several ones named Hinode, Namari, Fukurei, Taishô and so forth.

Taking the occurrence and genesis of ores into account, the deposits of the Yamato mine are roughly dividable into three kinds such as:

(a) Sulfide deposits derived metasomatically in massive occurrence, accompanying so-called skarn minerals,
(b) Sulfide deposits appeared as if they were produced as a sort of fissure-filling lodes, and
(c) Oxide deposits precipitated secondarily in caves or in fissures.

All of these deposits are however observed contained in oxidation zone and seem to have been subjected to secondary enrichment.

Dôtoko deposit: The deposit is found situating on the uppermost level in the southernmost part but its mode of occurrence is at present not discernible because of close of the gallery. According to SEKINE (1958), UENO and DOI (1956) it seems however that some massive bodies of sulfide ores associating skarn minerals assemble together and are arranged with a trend revealing strike of N 10°–30° E and dip of 50°–60° E, extension of 10–15 m along strike-side, general plunge of S 40° E with inclination of 40°, extension of about 30 m along plunge, and thickness of 5 m, while at the same time some oxide deposits are observed filling the fissures. These sulfide ores are in arrangement probably parallel to the Daidô deposit referred to in the following.

Daidô deposit: Whereas the deposit in question has been the largest in scale and most important of all, its lowermost part only is now being prospected and ex-

cavated because the whole mass was exhausted nearly at all.

The ores concerned have been excavated in several galleries such as Tsûten-kô, Hon-kô, Chūgiri-kô, Shinsei-kô and Hôkoku-kô which are situated from upper to lower levels in order and combined with one another through inclines within the ore body.

At the time of SUZUKI it seems that Tsûten-kô and Hon-kô were already abandoned, a little amount of ores filling the cracks of chert were only explorated along Chūgiri-kô which were almost mined at all, and Shinsei-kô was the main gallery for mining. Recently excavation for the part situating between the latter two levels has been promoted and resulted in connection with each other, its goaf revealing a giantic cave.

One of the principal ore bodies in this deposit is massive sulfide deposit derived metasomatically, accompanying skarn minerals. It may be that the deposit under consideration is divided in form into one situating in the part upper than Hon-kô and the other included between Chūgiri-kô and Shinsei-kô. Of the two, the former is, as has been stated, not confirmable in detail while the goaf of the latter discloses in shape a sort of pipe with S 60° E plunge with inclination of 15°–30° and with extension of about 120 m, becoming smaller in diameter from 25 m on the upper level to 5 m on the lower level. The ore body is however considered numerous aggregates of small-scaled, lenticular masses, because the actual occurrence pointing to the previous state is remained along its margins or in parts of the goaf. Its lowermost part comes in contact with a later fault with NS strike and eastward dip of low angle running along a little higher part of its hanging wall.

The fissure-filling deposits composed mainly of quartz veins associating sulfide ores are found developed downward from the level further lower than those mentioned above, pointing nearly to NS trend with dip of from 50°–40° E on the upper level to 35°–25° E on the lower level and to a plunge of S 50°–60° E with inclination of 20°–30°. These lodes are probably considered to be distributed in the parts situating between the level some what upper than the Minami-Uwanobe-kô of the Shinsei-kô and that lower than Hôkoku-kô and reveal extension of 60 m on the upper level and of 10 m on the lower level along strike-side as well as of more than 150 m along plunge but are not presumed to continue in the parts far deeper than the level of Hôkoku-kô. Their thickness is 1 m in maximum and those with thickness of more than 50 cm are now being mined.

Beside the two types mentioned above the Daidô deposits include that named the ore body No. 1, which is now impossible to be inspected because of being immersed in underground water. The latter is situated on the northern side of the ore body accompanying skarn minerals on the Chūgiri-kô level and composed merely of secondarily formed oxide minerals filling the caves of limestone and the fissures of chert, in the goaf of which any ores to be mined are now not remained at all.

Fukuju deposit: The deposit is the principal one which has recently been de-

veloped on a large scale and constructed complicatedly of masses of metasomatically produced sulfide ores associating a bulk of skarns and those of vein type. As be the case with the Daidô deposit, the massive ores are believed to have been prior to the lodes in stage. The ores concerned have been mined almost at all in the Fukuju-kô (256 m high above the sea-level) and in the Hôrai-kô (228 m high above the sea-level) combined with the former through inclined adits. Inspection of the empty goaf shows that the ore body is actually constructed of more than thirty-seven masses of various scale and shape, accompanying skarn minerals. Each of them reveals EW-N 30° E strike with eastward or southward dip of low angle in discordance with its southward or S 30° W plunge in low angle, resulting in formation of a flattened pipe-like ore body with S 35° W plunge in low angle on the whole, the width of which becomes more and more smaller with depth. The ore body is found cut across by EW fault in the northern part. Since the trend of this deposit is remarkably distinguished from those of Dôtoko and Daidô, the relations of these trends to geologic structures are in more details to be researched in connection with the space suitable for ore deposition.

Within the district a remarkable outcrop of ore deposit is appeared in the place situating between Daidô and Fukuju deposits as minor lodes of secondarily produced oxide minerals filling the fissures of chert whereas its inner part is remained to be clarified because of impossibility of standing in the underground gallery, e.g. the Hinode-kô running just through its lower level.

Circumstances of the galleries other than those referred to already are not known because of being impossible to stand in.

IV. Ore Minerals

In the Yamato mine, the ores bearing copper have been mined as the main objective and those of other sulfides as well as of tungsten have been also so on a certain scale. These ore minerals are, in relation to their genesis, divided into those remained as primarily formed state and the oxides derived secondarily from the former. In general both types are used to constructing the different bodies but happen to co-exist in parts in the oxidized zone.

As the ore minerals produced primarily, chalcopyrite, bornite, chalcocite, covelline, pyrite, pyrrhotite, arsenopyrite, sphalerite, galena, scheelite, molybdenite, magnetite and so on are mentionable. Their occurrence and assemblage are different from one another in each deposit or ore body. For instance, it seems common that chalcopyrite, pyrrhotite and some others are found as massive bodies surrounded with the skarns, as impregnations in the skarns, and as networks of veinlets penetrating the skarns or as massive bodies and impregnations without the skarns in chert, while these minerals are liable to be included in chert and in the part along the contact of chert with limestone but very scarcely in limestone.

Skarn minerals found around this kind of ore bodies are believed to have been

prior to the latter in stage of formation. Skarns recognized already are wollastonite, garnet, hedenbergite, vesuvianite, epidote, diopside, micas, tremolite, and so forth associated with subsequently formed actinolite, lievrite(?), kaolinite, etc.. Of all, wollastonite shows the widest, and various kinds of, distribution but in most cases occurs as networks of veinlets filling the fissures of chert, representing probably the earliest mineralization.

Arsenopyrite, sphalerite, galena and so on are used to occurring as fissure-filling lodes composed mainly of quartz relating to various stage of formation. The lodes of this type scarcely comprise pyrrhotite and indicate variation into those of galena and sphalerite accompanying the decreasing amount of chalcopyrite and the increasing amount of arsenopyrite with descending of the mineralization stage.

Scheelite and molybdenite are contained not in Fukuju deposit but in Daidô deposit wherein the former is found either in its middle part as impregnation in skarns or in its lower part as veinlets cutting across the lodes.

Besides, oxide minerals derived secondarily are represented by chrysocolla, malachite, azurite, limonite, cuprite, chalotrichite, native silver, native copper, chalcanthite, smithonite, gypsum, anglesite and so on.

V. Conclusive Remarks

Geological notes concerning the Ofuku district have been outlined and the ore deposits found in the Yamato mine have also been referred to somewhat in detail. As a result it has become clear that the latter might have been originated not simply from the pyrometasomatic effects of acidic intrusive on limestone, as was ordinarily suggested according to the previous category, but from more complicated processes of repeated mineralizations. There is however a room to scrutinize the relation of spaces and situation to ore genesis in the Daidô and Dôtoko deposits as well as in Fukuju deposit different from the former two. Both distribution and shapes of limestone observed in the galleries are also not so much simple as are drawn in geologic map but strikingly confused and probably cause, or rather result in, formation of weak lines or zones developed well specifically along or near its contact with chert. It seems also considerable that these parts might have been suitable for deposition of ores and furthermore re-activated to move, for example, as a low-angled fault which is reasonably believed to have been formed subsequent to genesis of the Daidô deposit and recognized at present on its hanging wall.

Genesis of the minerals mentioned in the preceding, their relations to wall rocks, and general relations of geology to the ore deposits will on the basis of detailed researches be enlightened in the following report.

Acknowledgement. The present authors wish to dedicate their cordial gratitude to Professor Y. Umegaki of the Hiroshima University, under whose guidance this study has been, and is being, put into practice, and to S. Nagatomi, Assistant

of his institute. They are also much obliged to Professor Y. KINOSAKI of the same university, who gave them many valuable suggestions concerning the ore deposits, to Messrs. H. SHIBATA, Sano High School of Engineering, K. KIMURA and R. NISHI, Osaka College of Liberal Arts, helping their field work, and to Messrs. T. NOJIMA, M. KUMASHIRO and Y. KAWAUCHI of the Yamato mine, giving convenience for field survery. It is to be added to that this study has been put into effect with aid of scientific research from the Ministry of Education of Japan.

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Explanation of Plate XLIX

All figures ×33.

Fig. 1. Biotite hornfels of silicious slate at the entrance of the Hōrai gallery. Lower nicol only.

Fig. 2. Porphyrite dike occurred on the southern side of the Sanjō mine. Crossed nicols.

Fig. 3. Small granodioritic apophysis appeared at the entrance of the Hōrai gallery. Lower nicol only.

Fig. 4. *ibid.* Crossed nicols.

Abbreviation

H.....Hornblende
O.....Orthoclase
P.....Plagioclase
Q.....Quartz

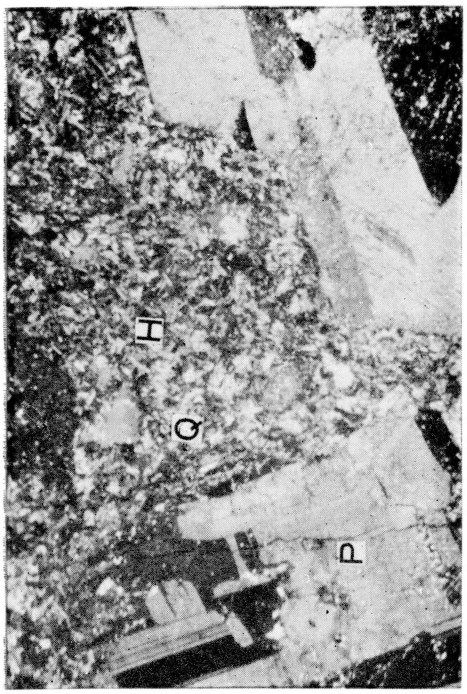

FIG. 2

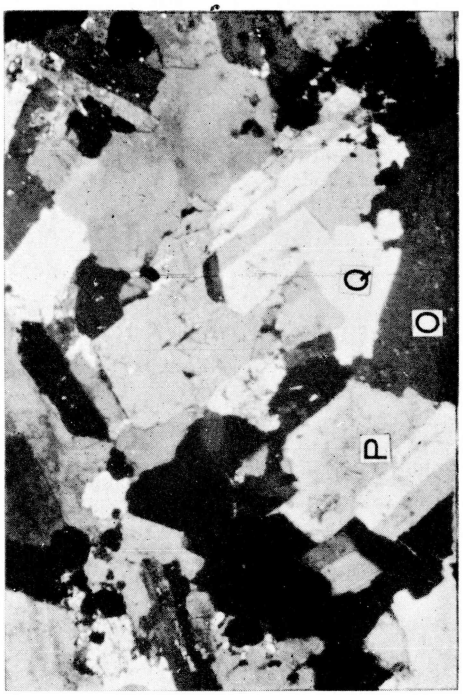

FIG. 4

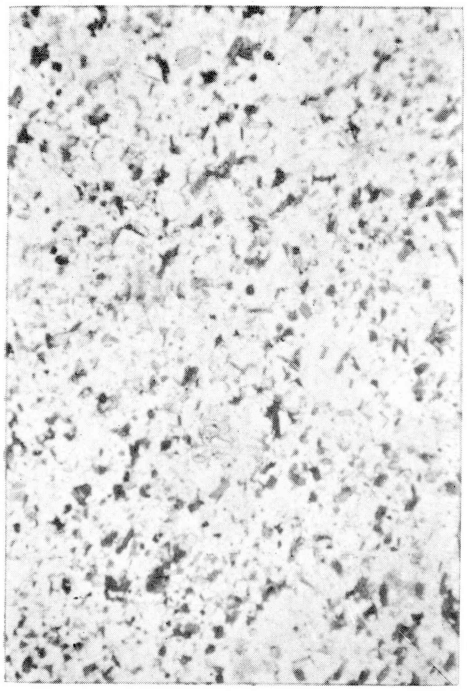

FIG. 1

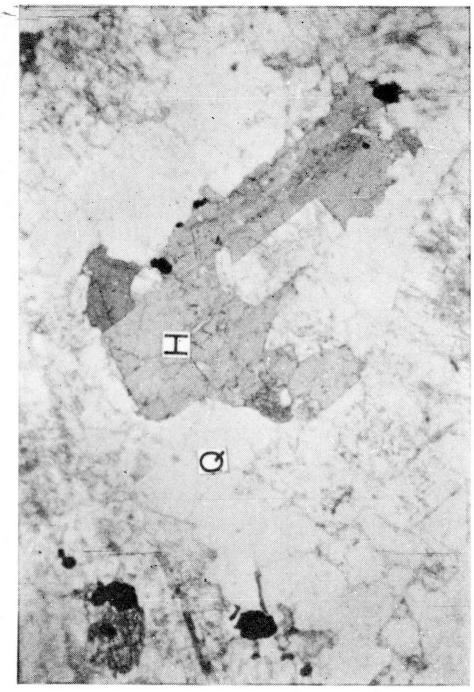

FIG. 3

Explanation of Plate L

All figures ×22.

Fig. 1. Marginal facies of granodioritic boss appeared on the road from Ofuku to Nishihata, north of the Yamato mine.
Fig. 2. *ibid.* Crossed nicols.
Fig. 3. Main facies of granodiorite appeared on the road from Ofuku to Nishihata, northeast of the Yamato mine.
Fig. 4. *ibid.* Crossed nicols.
Fig. 5. Granodioritic apophysis appeared at the quarry situating between the Fukurei and Fukushige mines. Lower nicol only.
Fig. 6. *ibid.* Crossed nicols.

Abbreviation

A.....Pyroxene (diopside ?)
B.....Biotite
H.....Hornblende
O.....Orthoclase
P.....Plagioclase
Q.....Quartz

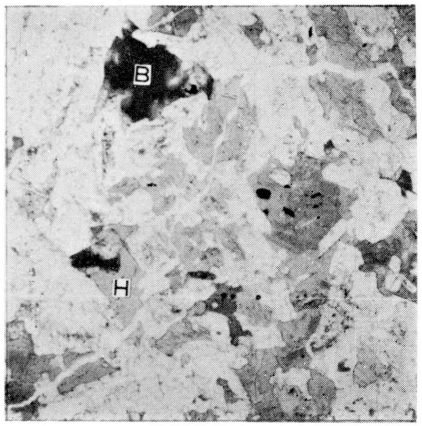

Fig. 1

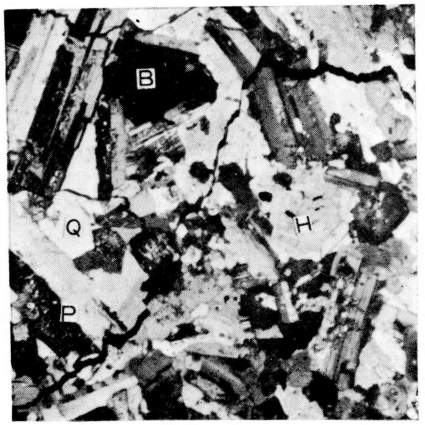

Fig. 2

Fig. 3

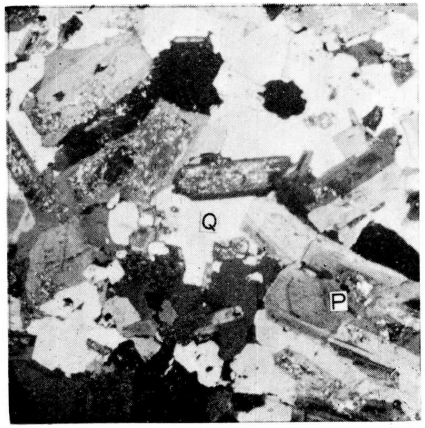

Fig. 4

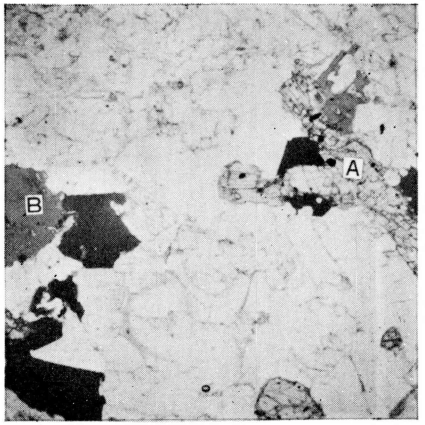

Fig. 5

Fig. 6