BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 38 (1960), pp. 479-495

30. *Xenoliths Included in Granitic Rocks of the Sekine-Azusayama District, Yamagata Prefecture.**

By Takeshi ICHIMURA.

(Read March 24, 1959.—Received September 22, 1960.)

Introduction

The granitic area of the Sekine-Azusayama district now included in Yonezawa City is characterized by the high frequency of xenoliths which have different characteristics and modes of occurrence (Fig. 1). The xenoliths exposed here are occasionally found extensively and in intricate manner (Fig. 2) when compared with those of other granitic areas of Yamagata Prefecture. They are represented by several kinds of rock, and some of them pass into one another without showing any sharp boundary between them.

Such geological and petrological features can be observed along the Haguro-gawa and Kariyasu-gawa as well as along their tributaries. The most remarkable one is to be seen at the lowermost course of the Kariyasu-gawa where various kinds of xenolith are well exposed and traversed intricately by granitic rocks.

The writer's field work started at this place and was extended to other parts of the district. Thus, the writer could examine many exposures throughout the whole area. Among them, those of the limestone quarry were very attractive, since he obtained from here abundant contact minerals due to the granitic intrusion. During that time, his laboratory work was carried out on the specimens collected from different localities.

General Features of Mother Rocks

In the beginning, it is necessary to give some explanation of granitic rocks which are known as the mother rocks of xenoliths (Fig. 3). They are represented by biotite granite, biotite granodiorite and hornblende biotite granodiorite.

Of these, biotite granite is always found in close association with

* Communicated by H. TSUYA.

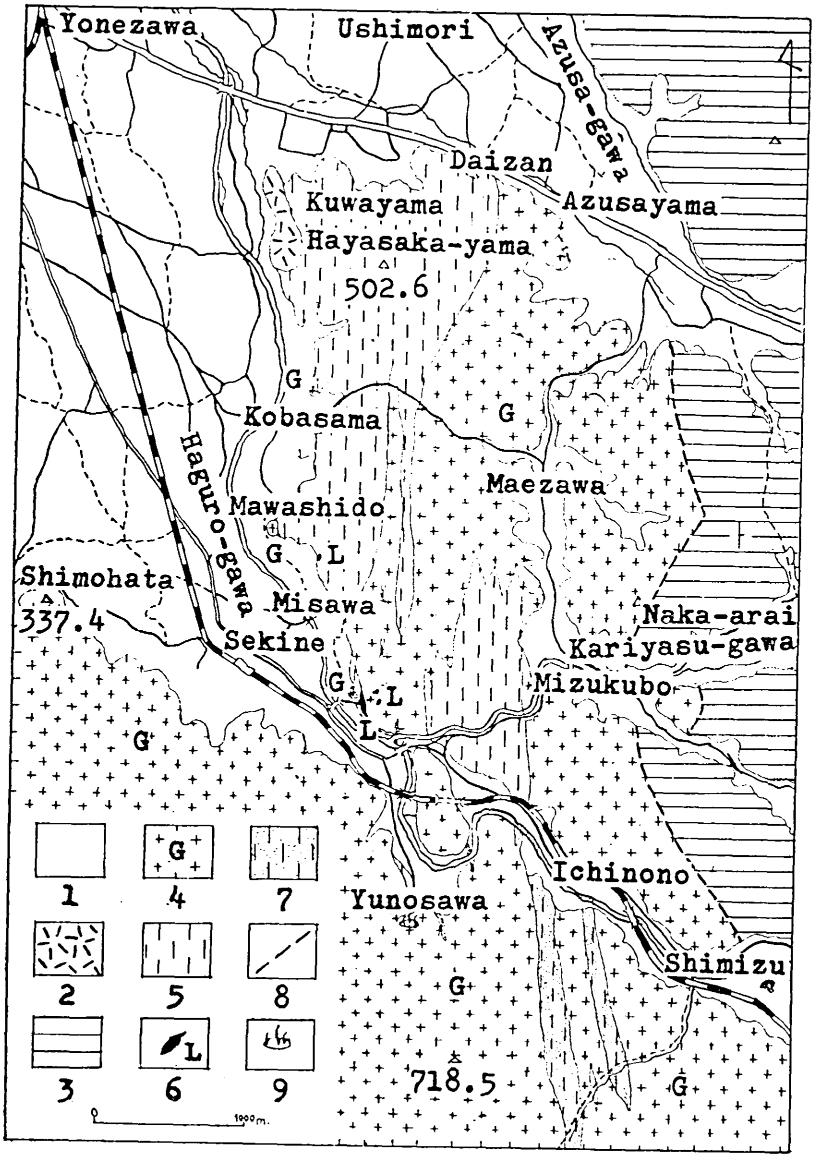

Fig. 1. Geological map of the Sekine-Azusayama district.

1. Quaternary fluviatile deposits, 2. Plagioliparite, 3. Miocene tuff, shale and sandstone, 4. Granite, granodiorite, pegmatite and aplite, 5. Quartz diorite and amphibolite associated with biotite schist and biotite gneiss, 6. Crystalline limestone, 7. Quartz diorite or biotite schist associated with biotite gneiss, 8. Fault, 9. Mineral spring.

xenoliths, and its occurrence is limited as comrared with that of granodiorite. It is a leaucocratic rock composed of quartz, orthoclase, microcline, plagioclase (oligoclase-andesine), biotite, magnetite, apatite, zircon, allanite, titanite, chlorite, sericite and limonite. One of the characteristic features of this rock is the high frequency of microcline and perthite.

Granodiorite is the most predominant rock in the Sekine-Azusayama district, it being first exposed near Daizan and extends southwards across the Ou Railway Line, forming the main part of the hilly land together with xenoliths and Miocene sediments, but on its eastern margin it is largely displaced against the Miocene formation (Fig. 1).

So far as is known at present, hornblende biotite granodiorite seems to pass into biotite granodiorite here and there without revealing any sharp boundary between them. Such a tendency can be observed at Misawa and the limestone quarry near Sekine as well as along the Haguro-gawa between Yunosawa and Ichinono. The same may be said of biotite granite, although it has not yet been confirmed by the writer.

Granodiorite is mostly a medium-grained or coarse-grained rock with such mineral ingredients as quartz, microcline, orthoclase, plagioclase (basic oligoclase—andesine), magnetite, apatite, zircon, titanite, epidote, goethite, limonite, chlorite and calcite (Table I, Fig. 7).

Table I. Essential mineral ingredients of granodiorite.

Quartz	Orthoclase	Microcline	Plagioclase	Biotite	Hornblende
Diameter =0.4mm. 1.8mm. Remarkably wavy extinction.	Very low in frequency. Occasionally shows a microperthitic structure. Smaller than plagioclase.	Low in frequency.	Abundant. Longer diameter=1.8mm −4.8mm. α(min.)=1.534 γ(max.)=1.556 An_{30-40} Partly alters to sericite. Inclusions= apatite, biotite, hornblende & magnetite.	Max. diameter on base=1.5 mm. $\gamma=1.655\pm$ X=light yellow, $X=Z=$ dark bown, Alters to chlorite. Inclusions= apatite, magnetite, zircon, allanite & titanite.	Max. diameter=14 mm. X=light yellow, Y=yellowish green, Z=green or bluish green. $Z>Y>X$. $Z\wedge c=15°-18°$. $\alpha=1.645-1.667$. $\gamma=1.661-1.682$. Partly changes into calcite, chlorite or epidote. Inclusions=apatite, magnetite, zircon, biotite & allanite.

Distribution and Modes of Occurrence of Xenoliths

The xenoliths of this granitic area are composed of amphibolite, biotite gneiss, biotite schist, crystalline limestone and quartz diorite. Of these, amphibolite and quartz diorite are found here and there through the whole area, but the distribution of biotite schist or biotite gneiss seems to be restricted to the southern half.

(1) Xenoliths of amphibolite and quartz diorite: These kinds of rock form a main part of the xenoliths exposed here, showing gradual or sudden transition from one to another, and they pass into biotite schist or biotite gneiss further southwards. The largest exposure is to be seen at the northwestern corner of the area which includes Kuwayama, Hayasaka-yama (502.6 m.), Kobasama, Mawashido and Misawa. It is traceable southwards down to the opposite side of Sekine where limestone has once been quarried.

Separated by granitic rocks, there is another exposure of a large xenolith which extends southwards across the Kariyasu-gawa and Haguro-gawa. The northern half of this xenolith consists of amphibolite, crystalline limestone and quartz diorite, but it is characterized by the appearance of biotite schist and biotite gneiss to the south. The best exposure is to be seen at the lowermost course of the Kariyasu-gawa (Fig. 2). As is shown on the river-bed and the cutting of the truck road, the xenolith of amphibolite and quartz diorite is intricately traversed by biotite granite, biotite pegmatite and other leucocratic rocks. Exclusive of pegmatite, these leucocratic rocks have an aplitic appearance, consisting of quartz, plagioclase, biotite, hornblende, magnetite, zircon, titanite, apatite and allanite. They occur as veinlets or irregular masses which have a narrow zone (5 mm.—3 cm. in width) poor in ferromagnesian minerals along the contact parts. It is also noteworthy that many xenoliths of quartz diorite, 30 cm.—2 m. in diameter, are sporadically included in the mother rock exposed near Ichinono. They can be observed on the river-bed of the Haguro-gawa. The xenoliths of this place are rounded or angular in form and are always bordered sharply against the mother rock. The swarms of such xenoliths of amphibolite and quartz diorite can be investigated at several places.

(2) Xenoliths of biotite schist and biotite gneiss: These two kinds of rock are sometimes found together with amphibolite or quartz diorite and increase in frequency to the south. The occurrence of biotite schist is known at Kuwayama and near the junction of the Haguro-gawa and Kariyasu-gawa (Fig. 4) as well as along a tributary of the Haguro-gawa branching off at the opposite side of Shimizu. Biotite gneiss is, on the other hand, exposed at Misawa, the lowermost course of the Kariyasu-gawa and Ichinono. When biotite schist and amphibolite are associated, the former reveals a gradual transition to the latter.

Xenoliths of crystalline limestone: There are several xenoliths of crystalline limestone, large and small, which are sporadically distributed in the area between Mawashido and the lowermost course of the Kari-yasu-gawa. They take a lenticular or irregular form, and some of them can be seen at the old limestone quarry near Sekine (Fig. 5). The largest one at this quarry is estimated to be about 300 m. in length, being included in granodiorite together with amphibolite, biotite schist and quartz diorite. It is intruded by hornblende pegmatite and biotite granite. The writer collected here various kinds of contact minerals. Moreover, the biotite granite of the same quarry contains three small xenoliths free of such contact minerals and amphibolite or quartz diorite (Fig. 6.). The occurrence of crystalline limestone is also noticed near Mawashido and along the tributaries of the Kariyasu-gawa branching off northwards or westwards. At these places, the main xenolithic rocks are amphibolite and quartz diorite.

Mineral Composition of Xenoliths

(1) Amphibolite: There are several types of amphibolite represented by compact and hard rocks with a black color. Some of them have a distinct schistosity and intricate structure, showing various textures under the microscope. They are composed of plagioclase, green hornblende, biotite, magnetite, epidote, titanite, zircon, rutile, apatite, limonite and tourmaline (Fig. 8). The frequency of these minerals varies to a remarkable extent in different specimens, with exclusion of green hornblende, plagioclase and magnetite.

One of the important ingredients is plagioclase with a subhedral or anhedral form. It ranges from basic andesine to acidic labradorite. When the mineral is not twinned but reveals a wavy extinction, its appearance resembles quartz to some extent.

In this rock, the most predominant mineral is the subhedral or anhedral hornblende with a long or stout prismatic habit. Frequently, it occurs in close association with biotite, although the latter is absent in the specimens collected from Kuwayama and Hayasaka-yama or elsewhere. The size of this mineral seems generally to increase along the contact parts where the rock passes into quartz diorite or granodiorite.

The quantity of biotite is subordinate as compared with green hornblende and has a tendency to decrease in the specimens from the northern half of the area. The relationship between this mineral and green hornblende is clearly evident at the lowermost course of the Kariyasu-gawa. The amphibolite exposed here is mostly rich in biotite flakes and grades into biotite schist. A similar tendency can be seen at the old limestone quarry.

Magnetite is a mineral common to all specimens and takes generally an octahedral or irregular form. In the latter case, it is occasionally represented by a skeletal crystal. The writer has collected some specimens rich in magnetite from near Hayasaka-yama and Kuwayama as well as from the lowermost course of the Kariyasu-gawa. Some of it is included by hornblende or oligoclase or biotite and fills up the interstices between them. The crystal is usually 0.01 mm.—0.08 mm. in diameter.

The occurrence of epidote seems to be restricted to the specimens from Misawa and the valley entering westwards from Mizukubo. The crystal is subhedral or anhedral and prismatic or granular, producing some confused aggregates. The largest one is 0.43 m. long and 0.25 mm. across. In such a case, the angle between Z and (100) is estimated to be 30°.

Titanite is also one of the accessory ingredients frequently contained in the specimens from near Mizukubo and the lowermost course of the Kariyasu-gawa. Its minute crystal takes an irregular form, being intermixed with hornblende or biotite and being characterized by its high birefringence and relief. As can be observed in some thin sections, magnetite is surrounded by this mineral.

Besides them, a noteworthy feature is the presence of tourmaline in the specimens from the eastern side of Hayasaka-yama. The mineral is found as a phenoblast which is always anhedral in its crystal form. It is distinctly pleochroic from light yellowish brown (X) to yellowish brown (Z) at the periphery, but from light blue (X) to blue (Z) at the core. The largest crystal is 1.44 mm. long and 0.85 mm. across. The enclosure is magnetite, limonite and hornblende.

Table II. Essential mineral ingredients of amphibolite.

Plagioclase	Hornblende	Biotite
Mostly, 0.02mm.−0.08 mm. in longer diameter. $\alpha=1.551\pm$ $\gamma=1.560\pm$ $An_{45}\pm$	Generally, 0.7 mm. ± in longer diameter. The largest one is 1.02mm. long and 0.34 mm. across. $\alpha=1.648-1.660$ $\gamma=1.662-1.672$ X=light yellow. Y=yellowish green or green. Z=green or dark green. $Z\wedge c=18°-25°$	0.3 mm−0.5 mm. in diameter (base). $\gamma=1.650\pm$ Pleochroism is weaker than that of granodiorite.

Zircon, rutile, apatite and limonite are contained in minor quantity.

(2) Biotite schist: This rock is frequently exposed in close association with amphibolite or biotite gneiss and reveals occasionally a gradual transition between them. It has a black color and distinct schistosity, consisting of such mineral ingredients as quartz, microcline, orthoclase, plagioclase, biotite, muscovite, hornblende, magnetite, zircon, epidote, chlorite and limonite (Fig. 9).

One of the important minerals is quartz composed of irregular or somewhat round crystals which are found in a mosaic or interdented structure. Mostly, it shows a strain shadow and is characterized by an abundance of liquid inclusions. The largest crystal is 1.7 mm. in diameter.

Microcline and orthoclase are, on the other hand, very rare ingredients. The occurrence of these minerals are known only in the specimens obtained from near the junction of the Haguro-gawa and Kariyasu-gawa. They are represented by minute subhedral or anhedral crystals, the longer diameter of the largest one being 0.25 mm. in microcline and 0.29 mm. in orthoclase respectively. In the case of orthoclase, a microperthitic structure is usual.

Plagioclase is a common ingredient in almost all specimens and belongs to andesine or labradorite. The crystal is subhedral or anhedral, and its longer diameter is estimated to be 0.5 mm. in the largest crystal.

The tabular crystals or irregular flakes of biotite occur in a parallel arrangement. They are strongly pleochroic from light yellow or light brown (X) to dark brown or reddish brown (Y or Z). In this case, the index of refraction, γ, is 1.644—1.650. Such biotite crystals enclose mostly magnetite and are sometimes chloritized. The diameter of the largest one is 2 mm. on (001). Muscovite is, however, low in frequency when compared with biotite. Its crystal is scattered here and there in quartz layers and lenses, forming sporadically some confused aggregates.

Hornblende is always absent in type specimens, but begins to appear in those exposed close to amphibolite. It has a pleochroism which changes from light yellow (X) to yellowish green (Y) or deep green (Z).

Octahedral or skeletal magnetite is a noticeable mineral in the specimens from the limestone quarry near Sekine, but it is almost or entirely absent in other cases. The crystal has a diameter of 0.01 mm. —0.08 mm., and some of it passes into limonite.

Zircon and apatite are present to a negligible degree. The same may be said of epidote which traverses the rock as a veinlet.

(3) Biotite gneiss: This rock has a coarse banded structure due to

the repetition of the parts rich in biotite and quartzose layers. At a glance, it looks like the Ryōke or Tsukuba metamorphosed sediments. Under the microscope, the rock is composed of quartz, microcline, orthoclase, biotite, muscovite, magnetite and zircon.

Of these, quartz is the predominant mineral, showing a mosaic or interdented structure. The crystal is 0.85 mm. in the maximum diameter and indicates a strain shadow in each grain. It is usually rich in such inclusions as muscovite, biotite, magnetite and liquid (?).

In contrast with the quartz, microcline and orthoclase are poorly present. The same tendency is also to be seen in the case of plagioclase, as is indicated in the specimen from near Ichinono.

Biotite and muscovite are abundant in all thin sections, both being intricately intermixed in a parallel arrangement. The former is strongly pleochroic from light brown (X) to reddish brown (Y or Z) and includes magnetite and zircon, whereas the latter is found as a flaky aggregate and contains magnetite.

Magnetite takes an irregular form and is mostly associated closely with biotite or muscovite in which it occurs as inclusions.

The occurrence of zircon is generally restricted to small quantities. When its rounded crystal is contained in biotite, it is characterized by the formation of a pleochroic halo.

(4) Crystalline limestone: This type of limestone has a greyish white or white color and is a fine to coarse-grained rock with a saccharoid appearance due to recrystallization. It is generally composed of calcite and several other kinds of minerals. One of its characteristic features can be seen in the specimens obtained from the old limestone quarry near Sekine where the rock contains such minerals as diopside, epidote, garnet, green hornblende, plagioclase, pyrrhotite, sericite, titanite, tremolite and vesuvianite.

Under the microscope, diopside is not as abundant as garnet, being commonly associated with epidote, garnet and vesuvianite and giving a light or dark green color to the mother rock. In this case, the crystal is subhedral or anhedral. The largest is 2.39 mm. long and 1.53 mm. across. When the mineral is found together with garnet, the interstices of the latter are sometimes filled by the former. The extinction angle, $Z \wedge c$, is 39°. Twinned crystals are unknown in the writer's specimens.

Epidote is contained in low frequency when compared with garnet and vesuvianite. It is occasionally found in an aggregate of elongated crystals in which the largest one is estimated to be about 30 cm. in length. The mineral has a dark yellowish green color in fresh specimens, but obtains a brownish shade when decomposed, being slightly pleochroic from colorless (X) to light yellow (Z). The crystal has a perfect cleavage parallel to (001) and twins on (100). The extinction angle $X \wedge c$, is 4°.

Garnet (grossularite) is the most predominant mineral except calcite which constructs the main part of the mother rock. This mineral has a light brown or yellowish green color and a greasy luster. The crystal is represented by a combination of (110) and (211). The largest one is about 2 cm. in diameter. It occurs usually as irregular masses or bands, but occasionally forms dots in the mosaic aggregate of calcite.

Pyrrhotite is, however, a mineral of low frequency. It has an irregular form and is always associated with calcite and garnet.

A similar frequency is also indicated by titanite, the crystal taking an irregular or rounded form. In the latter case, it has mostly an imperfect rhombic section. The mineral is characterized by high refringence and relief.

So far as is known at present, the occurrence of tremolite is restricted to a small quantity. The mineral has a white color and forms a radial aggregate on the surface of the massive garnet where its fiber is about 3 cm. in the maximum length. It twins on (100), and the extinction angle, $Z \wedge c$, is 15° or thereabouts.

In contrast with the three minerals mentioned above, a remarkable occurrence of vesuvianite is known to be present in many of the specimens from here. The mineral is easily distinguishable from other lime silicates by its brownish black color and greasy luster as well as by its poor cleavage. The crystal shows a high relief, but low in birefringence, being abnormally biaxial and negative.

Plagioclase, sericite and green hornblende are in negligible amounts.

(5) Quartz diorite: It is composed of biotite hornblende or hornblende biotite quartz diorite, hornblende quartz diorite and biotite quartz diorite. Among them, biotite hornblende quartz diorite is most predominant, consisting of quartz, plagioclase, hornblende, biotite, magnetite, apatite, titanite, zircon, sericite, chlorite and calcite (Figs. 8, 10).

In these cases, quartz has an irregular form and fills up the interstices of other mineral ingredients. This mineral is characterized by its remarkable strain shadow and abundance of liquid inclusions.

The most important mineral in quartz diorite is plagioclase whch ranges from acidic andesine to basic andesine. The crystal is subhedral or anhedral and takes a tabular form. It has a zonal structure, and its inner part is frequently sericitized intensely. Apatite, zircon, magnetite and titanite are sometimes included.

Subhedral or anhedral hornblende is found in high frequency except in biotite quartz diorite. It is green hornblende and twins occasionally on (100). The crystal contains magnetite, zircon and apatite, some of it being altered to chlorite and calcite.

Next to hornblende, another noticeable forromagnesian mineral is biotite, although it is lacking in some specimens from the Kariyasu-gawa and Haguro-gawa near Ichinono. The frequency of biotite varies from place to place. This mineral is occasionally more abundant than hornblende. Such inclusions as zircon, magnetite, titanite and apatite are seen in some crystals which are partly chloritized.

The minute apatite crystal is present almost in all thin sections. Its crystal has a long or short prismatic habit, and the largest one is 0.35 mm. in length. Magnetite is more or less titaniferous and some skeletal crystal is surrounded by a narrow zone of titanite. Its largest crystal is 0.59 mm. in diameter. Titanite is also a common accessory ingredient. This mineral is present to a remarkable degree in a specimen obtained on the river-bed of the Kariyasu-gawa. It has an irregular form and is sometimes associated closely with magnetite. The largest one is 1.19 mm. in its longer diameter.

The occurrence of zircon is rare. Mostly, it takes a granular form, but is occasionally prismatic. In biotite, a pleochroic halo is formed around the crystal. Chlorite is usually derived from biotite or hornblende, whereas sericite is an alteration product of plagioclase. Calcite occurs rarely as the secondary mineral of hornblende.

Table III. Essential mineral ingredients of quartz diorite.

Quartz	Plagioclase	Biotite	Hornblende
Generally, low in frequency Diameter=0.3 mm.–1 mm.	1 mm. long and 0.7 mm. across in the largest crystal. α(min.)=1.547 γ(max.)=1.560 An_{36-45}	0.6 mm. in the maximum diameter (base). γ=1.662–1.672 X=light yellow. Y=Z=dark brown.	Mostly, 0.7mm. ± in length. α=1.648–1.660 γ=1.662–1.672 $Z \wedge c=16°$ X=light yellow. Y=yellowsh green. Z=dark green. $Z>Y>X$

Chemical Composition

As to the chemical characters of granite and granodiorite, there are only two available data at present. They are shown in Table IV.

Table IV. Chemical composition (weight %), norm and Niggli value of granitic rocks.

Weight %	I	II
SiO_2	68.67	69.04
TiO_2	0.41	0.39
Al_2O_3	14.97	15.12
Fe_2O_3	1.41	1.28
FeO	2.63	2.43
MnO	0.11	0.08
MgO	2.04	1.78
CaO	3.83	4.11
Na_2O	2.68	2.74
K_2O	2.91	2.35
$H_2O(+)$	0.67	0.71
$H_2O(-)$	0.49	0.42
P_2O_5	0.09	0.13
Total	100.91	100.58

Niggli value	I	II
al	37.0	38.0
fm	27.0	25.0
c	17.5	19.0
alk	18.5	18.0
k	0.41	0.36
mg	0.48	0.47
qz	113.5	112.0
c/fm	0.46	0.76

Norm	I	II
Q	29.70	31.80
Or	17.23	13.90
Ab	22.53	23.06
An	18.07	19.46
C	0.92	1.08
Fs	3.30	2.90
En	5.10	4.50
Mt	2.09	1.85
Il	0.76	0.76
Ap	0.34	0.34

I=Biotite granite from the lowermost course of the Kariyasu-gawa.

II=Hornblende biotite granodiorite from the river-bed of the Haguro-gawa near the limestone quarry.

Analyst, T. Tōkairin.

Among several kinds of xenolith, amphibolite and quartz diorite were selected for chemical investigation, since they are more important than others and there are some geological problems concerning the original

Table V. Chemical composition (weight %), norm and Niggli value of amphibolite and quartz diorite from the Sekine-Azusayama district.

Wt. %			
I	II	II	III
SiO_2	62.41	51.43	52.08
TiO_2	0.78	0.35	0.31
Al_2O_3	15.01	17.92	17.65
Fe_2O_3	4.04	1.45	1.21
FeO	3.41	5.07	4.88
MnO	0.02	0.19	0.14
MgO	3.26	7.83	7.51
CaO	3.64	12.40	11.87
Na_2O	3.30	2.65	3.06
K_2O	2.75	0.39	0.53
$H_2O(+)$	0.81	0.45	0.39
$H_2O(-)$	0.22	0.12	0.21
P_2O_5	0.22	0.12	0.10
Total	99.86	100.37	99.94

Niggli value			
	I	II	II
al	31.0	25.0	24.0
fm	38.0	39.0	38.5
c	13.5	30.0	29.5
alk	17.5	6.0	8.0
k	0.36	0.09	0.11
mg	0.46	0.68	0.69
qz	50.0	−7.0	−8.0
c/fm	0.36	0.77	0.77

Norm			
	I	II	III
Q	20.16		
Or	16.12	2.22	3.34
Ab	27.77	22.53	25.68
An	16.30	35.20	32.80
C	0.61		
Fs	1.58	6.20	5.41
En	8.20	15.70	13.10
Wo		10.56	10.56
Fa		1.33	1.73
Fo		2.73	3.99
Ap	0.67	0.34	0.34
Mt	5.80	2.09	1.86
Il	1.52	0.61	0.61

I=Biotite hornblende quartz diorite from the lowermost course of the Kariyasu-gawa.

II=Biotite amphibolite from the lowermost course of the Kariyasu-gawa.

III=Amphibolite from near Misawa.

Analyst, T. Tōkairin

rocks. The results of chemical analyses thus obtained are shown in Table V.

In this table, No. I is the type-specimen of quartz diorite which is widely distributed together with amphibolite. It is rich in biotite and hornblende. No. II also contains biotite, whereas No. III is quite free of this mineral.

Chemically speaking, two such kinds of amphibolite are similar to some of the Formosan amphibolite investigated by the writer,[1] but are more acidic than that of the Takanuki district.

Origin of Quartz Diorite

One of the interesting geological features is the relationship between quartz diorite and amphibolite. It resembles partly that of the Takanuki district[2] where the Takanuki series[3] is extensively exposed. According to Ogura's investigations,[4] quartz diorite and amphibolite of the Takanuki district are closely associated and pass into one another with a gradual transition between them. In this case, quartz diorite has the same schistosity as amphibolite and changes its texture from fine to coarse as it departs from the amphibolite. Thus, he attributed the origin of quartz diorite exposed here to the result of the granitization of amphibolite.

In the Sekine-Azusayama district, quartz diorite is not only associated with amphibolite, but is frequently exposed in the areas of biotite schist or biotite gneiss and crystalline limestone. Besides these modes of occurrence, its xenoliths are independently contained in granodiorite.

When amphibolite is found together with quartz diorite, the former is complicatedly traversed by the latter (Fig. 2). Most of them are sharply bordered, but there are some exceptional instances of a gradual transition from one to another. Moreover, quartz diorite is always free of schistosity even near amphibolite, as is shown at the lowermost course of the Kariyasu-gawa.

In connection with the facts mentioned above, it is also noteworthy that the xenoliths composed of quartz diorite are abundantly contained in granodiorite in other areas of Yamagata Prefecture. For instance,

1) T. ICHIMURA, *Mem. Fac. Sc. Taihoku Imp. Univ.*, Ser. III, **1** (1944), 102-104.
2) Y. OGURA, *Jour. Geol. Soc. Japan*, **62** (1956), 616.
3) Geology and Mineral Resources of Japan, *Geol. Surv. Japan*, (1960), 124.
4) Y. OGURA, *op. cit.*, 610-614.

the writer observed them frequently along the Karasu-gawa (Gassan)[5] and Tachiya-gawa (Yamadera). They have a rounded or irregular form and are always represented by biotite hornblende quartz diorite with a mineral composition similar to the specimens from the Sekine-Azusayama district. There is, however, no evidence for determining the exact origion of this rock. The same mode of occurrence is to be seen along the upper course of the Haguro-gawa between Ichinono and Yunosawa, although it is restricted to a small extent. The xenoliths of the Sekine-Azusayama district are mostly characterized by the occurrence of various metamorphics closely associated. The origin of quartz diorite in the district under consideration is, therefore, much complicated as compared with the case of the Takanuki district, but it is impossible to overlook the effect of granitization.

Formation of Metamorphics

Various kinds of metamorphic rock are still preserved in granodiorite or granite exposed largely on the Backbone Range and in its vicinity including such prefectures as Yamagata, Miyagi and Fukushima. They are found as isolated formations or xenoliths composed mostly of biotite schist and biotite gneiss.

The occurrence of amphibolite and crystalline limestone is, however, restricted only to the Sekine-Azusayama district. In this area, these rocks are always associated with biotite schist or biotite gneiss. Among them, the most characteristic rock is amphibolite which crops out in high frequency as compared with others. The rock passes gradually into biotite schist or biotite gneiss and is sometimes intercalated with crystalline limestone. Such a mode of occurrence suggests that it was metamorphosed from some tuffaceous rock. There is also a possibility of its having an igneous origin, as has been noticed by Ogura[6] in the same type of rock distributed extensively in the Takanuki district. This may be assumed from the result of chemical analyses carried out on the type speciments of amphibolite which were collected from the Sekine-Azusayama district. According to this investigation, its original rock seems to have been gabbroic or diabasic.

Amphibolite is a metamorphosed product of granitic intrusions as is the case of biotite schist, biotite gneiss and crystalline limestone. Of

5) T. ICHIMURA, *Bull. Earthq. Res. Inst. Univ. Tokyo,* **33** (1955), 422.
6) Y. OGURA, *op, cit.*, 612.

these, biotite schist and biotite greiss were probably formed in the same way as those of the formation which is traceable northwards or north-northwestwards at the southern foot of Kuriko-san rising at the boundary between Yamagata Prefecture and Fukushima Prefecture where metamorphism took place at the time of granitic intrusion.[7] It is, however, uncertain how many times such intrusions were repeated. The same may be said of granitic intrusions in the Sekine-Azusayama district where there are different kinds of granodiorite and other granitic rocks.

During these granitic intrusions, various kinds of older sediments were successively metamorphosed, resulting in the formation of biotite schist, biotite gneiss and crystalline limestone. In the same connection, some of such metamorphics are supposed to have been subjected to granitization.

Sources of Xenoliths

As has already been stated, the granite and granodiorite of the Sekine-Azusuyama district contain many xenoliths, large or small, composed of several kinds of rock. They are largely distributed with a trend of *N* or *NNW* and intricate features varying from place to place. All of these xenoliths are represented by metamorphic or hybrid rocks. In this case, some of them are undoubtedly of sedimentary origion, whereas others are supposed to have been derived from the basic intrusive or tuff. Hence, it is inferable that there had once been a large exposure of older rocks prior to the granitic intrusions which took place in the district under consideration.

In Yamagata Prefecture, the occurrence of older rocks is restricted to several districts where granodiorite is widely exposed, being mostly distributed as isolated formations or xenoliths. There is, therefore, no connection between them, and the absence of fossils renders them very difficult to confirm their geological age. Among them, those of Iide-san and the Oguni district may be assigned to the Permian from some evidence indicated by the similar formations in the neighbouring district of Niigata Prefecture. It is also noteworthy that most of the formations exposed in Yamagata Prefecture consist of clay-slate and sandstone which pass into hornfels and schist or injection gneiss towards the granitic contact. In the case of the Sekine-Azusayama district, older

7) N. Jimbo, Yamagata-ken Kozanshi, (1955), 3. Geological Map of Yamagata Prefecture (compiled by N. Jimbo), (1960).

rocks are somewhat different from those mentioned above.

So far as is known at present, this district seems to have formerly been built up of limestone, clay-slate and sandstone as well as of the basic intrusive or tuff. These rocks were greatly disturbed subsequently by the intrusions of granodiorite and associated intrusives. During that time, the older rocks are supposed to have been subjected to an intense metamorphism. The xenoliths now exposed here are probably erosion relics of roof pendants which had fallen into the granitic mass at that time.

Summary

(i) The Sekine-Azusayama district is a well-known area of granitic rocks which include various kinds of xenoliths composed of amphibolite, biotite schist, biotite gneiss, crystalline limestone and quartz diorite. They are extensively exposed in this district. Of these, the predominant xenoliths are those of amphibolite, biotite schist quartz diorite.

(ii) Such xenoliths, larger or small, have a trend of north or north-northwest, some of them passing into one another. So far as is known at present, amphibolite is found to a larger extent than biotite schist and biotite gneiss in the northern half of the area, but is *vice versa* at its southern half. Besides them, quartz diorite is mostly associated closely with these metamorphics, and crystalline limestone forms some lenticular masses in amphibolite.

(iii) From the facts mentioned above, it can be inferred that there had once been some large exposures of older rocks prior to granitic intrusions. Thus, the district seems to have been built up of clay-slate, shale, sandstone, limestone and basic intrusive or tuff.

(iv) These rocks were highly altered by repeated granitic intrusions, resulting in the formation of several types of metamorphics subjected partly to granitization.

(v) During and after the granitization and metamorphism, such alteration products were included in the granitic bodies. The xenoliths exposed largely in the Sekine-Azusayama district may, therefore, be erosion remnants of roof pendants fallen into them at that time.

Acknowledgments

The writer wishes to express his appreciation to Professor H. Tsuya

[Bull. Earthq. Res. Inst., Vol. 38, Pl. 22]

Fig. 2. Amphibolite traversed intricately by quartz diorite (light color) which passes into a leucocratic rock along its contact. These rocks are well exposed at the lowermost course of the Kariyasu-gawa.

(震研彙報 第三十八号 図版 市村)

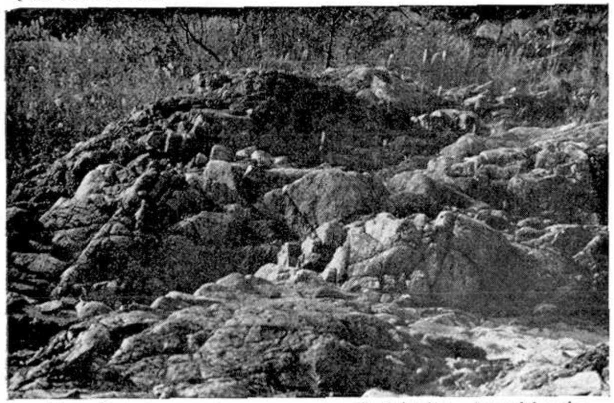

Fig. 3. A good exposure of biotite hornblende granodiorite along the Haguro-gawa.

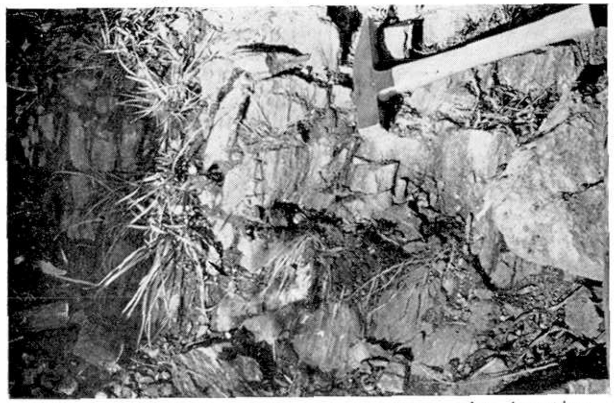

Fig. 4. Biotite schist exposed near the junction of the Haguro-gawa and Kariyasu-gawa.

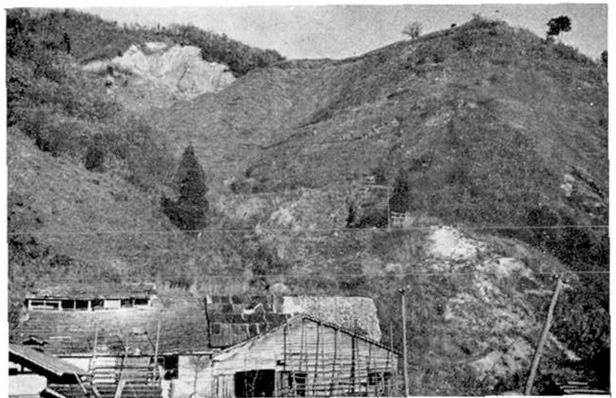

Fig. 5. The limestone quarry at the opposite side of Sekine.

Fig. 6. A xenolith of crystalline limestone in biotite granite exposed at the limestone quarry near Sekine. 1=Biotite granite, 2=Crystalline limestone.

(震研彙報 第三十八号 図版 市村)

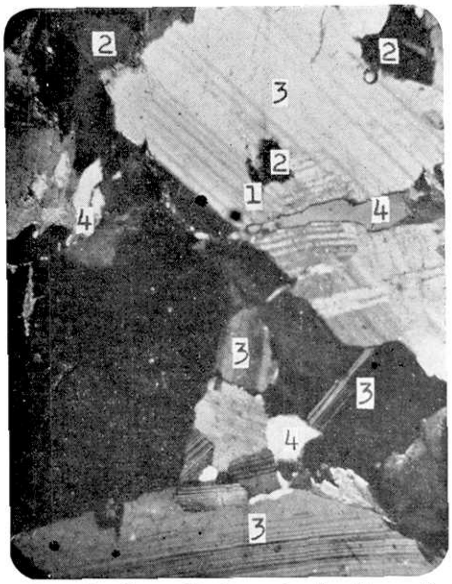

Fig. 7. Granodiorite, 1=Apatite, 2=Biotite, 3=Plagioclase, 4=Quartz (The lowermost course of the Kariyasu-gawa). ×100.

Fig. 8. Quartz diorite (right half, coarse) passing into amphibolite (left, half, fine). 1=Biotite, 2=Hornblende, 3=Plagioclase, 4=Quartz, 5=Titanite. (The Kariyasu-gawa). ×100.

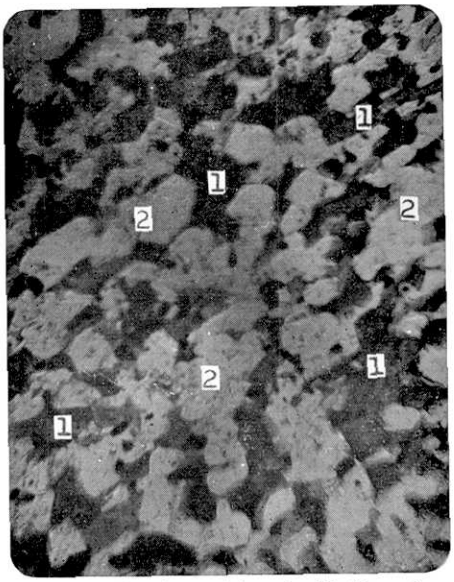

Fig. 9. Biotite schist. 1=Biotite, 2=Plagioclase and quartz. (The limestone quarry near Sekine). ×100.

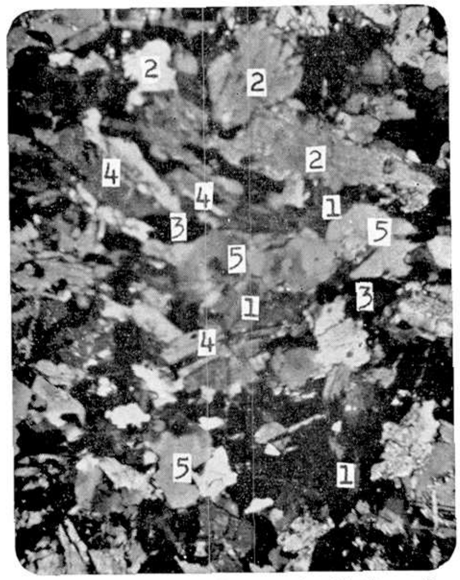

Fig. 10. Quartz diorite. 1=Biotite, 2=Hornblende, 3=Magnetite, 4=Plagiolcase, 5=Quartz. (The Kariysu-gawa). ×100.

（震研彙報 第三十八号 図版 市村）

and Mr. T. Tōkairin who facilitated the writer's laboratory work.

Thanks are also due to Miss H. Kanauchi for her co-operation in the writer's petrographical investigations of igneous and metamorphic rocks collected from the Sekine-Azusayama district.

---

30. 山形県関根・梓山地方の花崗質岩に含まれる捕獲岩

市 村 毅

関根・梓山地方に広く露出する花崗質岩には，いろいろな種類の捕獲岩が含まれている．これらは角閃岩，黒雲母片岩，黒雲母片麻岩，結晶石灰岩および石英閃緑岩よりなり，角閃岩，黒雲母片岩，石英閃緑岩などの捕獲岩が殊更多く認められる．その場合，結晶石灰岩は，角閃岩の間にレンズ状をなして挾在するか，直接黒雲母花崗岩中に不規則な塊をなし，時に柘榴石，透角閃石，ベスブ石，透輝石，緑簾石などを含むものも知られている．角閃岩，黒雲母片岩および石英閃緑岩は，しばしば相伴つて複雑な関係を示し，一方で角閃岩と黒雲母片岩とは，漸移する場合も少くない．また角閃岩と石英閃緑岩とは，一般に明瞭な境界を見せているが，まれに漸変的に移化して行くものもある．

以上の事実は，以前この地方に存在した粘板岩，頁岩，砂岩，石灰岩，凝灰岩あるいは塩基性化成岩が花崗質岩の大きな貫入によつて変成岩化し，他方では，花崗岩化作用のために，角閃岩その他が石英閃緑岩になつたことを物語つている．かくして生じた変成岩や石英閃緑岩の一部は，当時貫入を繰り返えした花崗岩体中に大小の岩塊または岩片として捕獲されるに至つたものと思われる．現在見られるのは，それらの侵触残骸である．
